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A

# TREATISE ON OPTICS;

OR,

LIGHT AND SIGHT,

THEORETICALLY AND PRACTICALLY TREATED;

WITH THE APPLICATION TO

FINE ART AND INDUSTRIAL PURSUITS.

By E. NUGENT, C. E.

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WITH ONE HUNDRED AND THREE ILLUSTRATIONS.

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1868.

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## PREFACE.

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THIS treatise on Optics is intended for all who desire to attain an accurate knowledge of one of the most interesting and useful branches of science.

The author has endeavoured to steer clear of all abstruse mathematical investigation and formulæ, so as to render the work easily understood by every intelligent reader.

Considering the great want of technical education among the industrial classes at the present time, and the immense utility to them of the knowledge of the principles of Optics, and of their application to the fine and industrial arts, it is hoped that this treatise will be found useful not only to artists, but to mechanics and artisans generally.

As a text-book for schools and colleges for both sexes, such a treatise, coming within the means of all, has long been a desideratum.

The author has spared no pains to embody all the most valuable discoveries in the science down to the present period, and to render the work as complete as possible, both in regard to the principles of

## PREFACE.

Optics and their application to the practical purposes of life.

The photographer will find numerous illustrations of the best and most recently-invented objectives, or lenses, and cameras by several of the most eminent makers in the world. The illustrations are, in many cases, of the real size of the objectives, and have been kindly furnished to the author, in several instances, by the makers themselves.

The painter and house-decorator, the milliner and dressmaker, the tailor and outfitter, will, one and all, find the principles of colour and their harmonious relation clearly explained; whilst the sculptor, the builder, the stonecutter, the mason, the draughtsman, the architect, the engineer—in short, all persons who may be engaged in any department of human industry—will find the work, it is hoped, worthy of careful study.

In no former period of the world's history was the truth of Lord Bacon's apothegm, "Knowledge is power," more apparent than it is in the present. Indeed, the apothegm may be paraphrased—*Knowledge is dollars*.

It is now a generally-admitted fact, that the material progress of a country depends, to a greater extent than ever before, on the knowledge of science and art possessed by its inhabitants. It is confidently hoped that this treatise will contribute to the diffusion of useful knowledge among the people, and consequently to their progress in wealth and happiness.

NEW YORK, Sept., 1868.

# OPTICS.

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## CHAPTER I.

OPTICS is the science which treats of vision, or seeing, and of the nature and properties of light—the changes which it undergoes in its qualities or direction when passing through bodies of different forms and substances, when reflected from their surfaces, or when moving past them at small distances.

Light is an emanation, or something which proceeds from bodies, and by means of which the external world is rendered manifest to the sense of sight. From the time of Socrates and Aristotle, down to the present day, or for a period of more than two thousand years, the most distinguished philosophers and scientific men have been divided in opinion as to its nature: one party has regarded it as consisting of material particles, or atoms, thrown off with great velocity from the luminous body, in all directions, and as affecting the organs of vision, or the eyes, somewhat in the same way as odours affect the organs of smell; the other party regards it as a fluid, or ether, diffused through all nature, and in which waves, or undulations, are produced by the action of the luminous body, and propagated in a manner somewhat similar to that of sound

through the air. This latter theory is now held by the greater number of scientific men who have devoted attention to the subject. In the Mosaic history of the creation, we find that light was created on the first day, and the sun, which we are accustomed to consider as the great source of light, on the fourth day. The Holy Bible declares, in simple and sublime conciseness, "And God said, Let there be light, and there was light." Thus emphatically declaring the importance of this element in the great system of nature.

But however *savans* may differ respecting the origin of light, and the manner in which it passes from one place to another, it has certain most useful and general properties, which have been discovered by observation and experiment. The grass, the herb yielding seed, and the fruit-tree yielding fruit, owe their germination, their growth, their resplendent colours, and their exquisite beauty, to the influences of the solar beams. The moving creatures of the waters, the birds that fly above the earth in the open firmament of heaven, the cattle, and the creeping thing, are, one and all, directly dependent for healthful vigour, and the continuance of life, on solar power, which seems to have given form to the chaotic earth as it dispelled the darkness from the face of the deep.

As it is by the influence of light, acting through the wonderful mechanism of the eye, that a most extensive and important class of impressions are made on the mind of man, he has, from the early dawn of creation, in his untutored and uncivilised state, rendered homage and adoration to the sun, as the apparent source and fountain of light.

In the early ages of mankind all natural phenomena were viewed through a veil woven of threads of mysti-

cism and superstition, which no one ventured to draw aside, or dreamed of lifting up.

At length a spirit of inquiry germinated in the mind of man; he commenced to speculate on the mysteries by which he was environed; his first efforts "were like the gropings of the blind Cyclops in his cavern," and when searching for the light of truth, he often wandered into darkness.

Among those who were first called philosophers there was a doubt whether external objects were rendered visible by means of something which proceeded from them to the eye of the spectator, or of something else that issued from the eye of the spectator to external objects. It was the opinion of Pythagoras, that vision is caused by particles continually flying off from the surfaces of bodies, and entering the pupil of the eye; but Plato and Empedocles supposed that the cause of vision is something emanating from the eye, which, meeting with something else that proceeds from the object, is thereby reflected back again. Aristotle maintained, in opposition, as he says, to the opinion of Empedocles and others, that light is incorporeal. If it were not a mere quality, but a real substance, the motion of it, he says, could not be insensible, in passing from the east to the west, though it might escape our notice in a smaller distance. The Platonic philosophers were acquainted with two important properties of light, viz., that light, from whatever it proceeds, is propagated in right lines, and that when it is reflected from the surfaces of polished bodies, the angle of incidence is equal to the angle of reflexion. Among other questions propounded by Aristotle, we find one concerning the reason why a straight stick appears bent when it is held obliquely in water; and Seneca says, that if the

light of the sun shine through an angular piece of glass, it will give all the colours of the rainbow. But, without investigating the nature of the phenomenon, he contents himself with saying, that this appearance is not of any *real*, but only a species of *false colour*, such as is seen in the neck of a pigeon, which changes with the position. We thus find that the *refraction*, as well as the *reflexion of light*, had not escaped the notice of the ancients. In a treatise on Optics, ascribed to Euclid, there is an attempt made to explain the phenomenon of the image of an object appearing as if it were suspended in the air, between the spectator and a concave mirror; and also an attempt to determine the size and figure of objects, from the angle under which they appear, or that the extremities of them subtend at the eye. The magnifying power of concave mirrors is mentioned both by Seneca and Pliny. It is probable that the ancient Romans and Druids had a method of lighting their sacred fire by means of reflecting concave speculums, and it is related by historians that Archimedes burned the Roman fleet by mirrors. Ptolemy, who lived about 150 years after Christ, was acquainted with atmospheric refraction, and of its being the cause of the sun, moon, and stars appearing higher in the heavens than they would otherwise do. From the days of Ptolemy down to the time of Alhazen, an Arabian philosopher who lived in the twelfth century, a great chasm is found in the history of optics. Alhazen gives a tolerable description of the eye, and treats largely of the nature of vision; maintaining that the crystalline humour is of principal use for this purpose, but without considering it as a lens; and asserting that vision is not completed till the impressions of external objects are conveyed by the optic

nerve to the brain. He accounts for single vision by two eyes by supposing that when two corresponding parts of the retina are affected, the mind perceives but one image; and he first advanced the opinion that the stars are sometimes seen above the horizon by means of refraction, when they are really below it, and also that the cause of the twinkling of the stars is refraction.

From the writings of Alhazen and some imperfect experiments of Roger Bacon subsequently made, it is probable that the construction of spectacles was hit upon by Salvinus Armatus, a nobleman of Florence, who died in 1317. In the year 1311 a work was written by Theodoric, in which a rational explanation of the double rainbow is given. In 1575 a treatise called "*De Lumine et Umbrâ*" was published by Maurolycus, teacher of mathematics at Messina, in which he demonstrates that the crystalline humour of the eye is a lens that collects the rays of light issuing from external objects, and throws them upon the retina. He showed that the defects called long-sightedness and short-sightedness proceeded from too small or too great a refracting power in the eye; and that in the former case the pencils of rays do not converge fast enough, so that the foci are beyond the retina; and in the latter that the rays converge too fast, and come to a focus before they reach the retina; and further showed how and why these defects were remedied by the use of convex and concave lenses. He failed to discover the formation of the picture of external objects on the retina, which discovery was afterwards first made by Kepler in 1604.

About the time that Maurolycus made his discovery of the nature of vision, Baptista Porta, a Neapolitan philosopher, invented the camera-obscura, which threw

still more light on the same subject. The invention of the camera-obscura suggested to Kircher the invention of the magic lantern, which does that in the night that the camera does in the day. Porta observed that the pupil is contracted involuntarily when it is exposed to a strong light, and expands when the light is small. He was mistaken, however, in his opinion concerning the cause of single vision with two eyes, for he states we never see with more than one eye at one time. The accumulated facts and experiments furnished by various scientific men, and the numerous suggestions of writers on optics, on the construction and use of lenses, and their combinations, had now prepared the way for the construction of telescopes and microscopes. The approach to the construction of the telescope was so gradual that the honour of its invention cannot be exclusively ascribed to any one person. It is, however, generally admitted that to Jansen, a spectacle-maker of Middleburgh, the greater share of the credit is due. The first telescope was made by him in 1590. He had no sooner found the arrangement of lenses that produced the desired effect than he enclosed them in a tube, and ran with his instrument to Prince Maurice of Nassau, who immediately conceiving that it might be of use to him in his wars, desired the maker to keep it a secret. But this was found impossible, though attempted for some time.

Among those who applied the telescope to the great ends of astronomical science, the name of Galileo stands foremost. He made a telescope himself which magnified about thirty times, and with which he discovered the satellites of Jupiter, the solar spots, and that the milky way and nebulae consisted of a vast number of fixed stars, which, on account of their great

distance or extreme smallness, were invisible to the naked eye. Subsequently he discovered that the planet Venus changes her phases like the moon.

Kepler suggested important improvements in the construction of telescopes; he also very clearly explained in a most scientific manner the principles of the instrument. He attributed erect vision from an inverted image on the retina to an operation of the mind beyond our power to understand. To him also is due the discovery of the great law of motion of the heavenly bodies, viz., that the squares of the periodical times are as the cubes of the mean distances from the bodies about which they revolve.

At the period to which we now refer, the beginning of the seventeenth century, the subject of the refraction of the atmosphere received a great deal of attention from scientific men, particularly from Tycho Brahe, who, perceiving the importance of it to the perfection of astronomy, applied himself diligently to it. He determined the amount of atmospheric refractions, at certain altitudes, to a tolerable degree of correctness. The honour of the discovery of the law of refraction, like many other important discoveries, cannot be exclusively ascribed to any one person, undoubtedly Snellius deserves a large share of the honour; it is to Descartes that we are indebted for the best exposition of the law of refraction.

## CHAPTER II.

## REFRACTION OF LIGHT.

ALTHOUGH a ray of light will always move in the same straight line when it is not obstructed, yet many persons must have noticed that when the light falls on a drop of water, or a piece of glass, or a vial containing any fluid which allows the light to pass, it does not reach the eye or illuminate a piece of paper placed behind those bodies in the same manner as before they were put in its way. This evidently is caused by some power which resides in the body of changing the direction of the light. The branch of optics that explains the law according to which the direction of the light is thus changed is called dioptics, from two Greek words, one of which signifies *through*, and the other to *see*, because the bodies which cause this change in the direction of light are those through which we can see or through which light passes.

In order to illustrate how this change or bending of light, is produced, let  $w x y z$  (Fig. 1) represent a

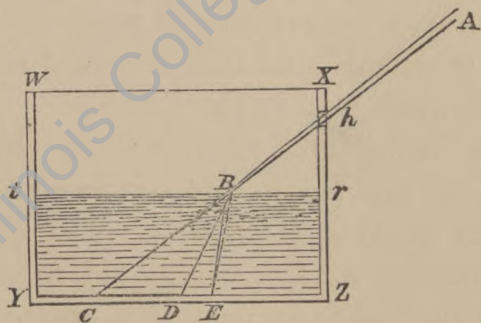


Fig. 1.

vessel, in one side of which,  $x z$ , there is a small hole  $h$ .

If we place a lighted candle within two or three feet of it, so that its flame may be at  $A$ , a ray of light,  $Ah$ , proceeding from it will pass through the hole  $h$ , and continue in a straight line,  $AhBc$ , till it reaches the bottom of the vessel at  $c$ , where it will form a bright spot. Having made a mark at  $c$ , let water be poured into the vessel till it rise to the height  $tr$ , and it will be seen that the spot which was before at  $c$  is now at  $D$ ; that is, the ray  $Ah$ , which went straight on to  $c$  when the vessel was empty, has been bent at the point  $B$ , where it falls on the water, into the line  $BD$ . If a little soap be mixed with the water, so as to give it a slight mistiness, the ray  $BD$  will be distinctly perceived to be a straight line, and that the bending or change in its direction has been produced entirely at the point  $B$  at the surface of the water. This bending of the ray  $AhB$  is called refraction, from a Latin word, which means breaking back, because the ray  $AhB$  seems to be broken back from its course at  $B$ , and the water is said to refract or break back the ray  $AhB$ .

If we pour salt water in the vessel instead of fresh water, we shall find that the ray  $AhB$  is more bent at  $B$ . If alcohol be poured in, it will refract the ray more than salt water, and oil more than alcohol. If a piece of glass the exact shape of the water were placed in the vessel, we should find that it would refract the ray still more than oil, and in the line  $BE$ .

By these facts, and many others that might be mentioned, we are led to the conclusion that when a ray of light passing through air falls in a slanting direction upon the surface of a liquid, or of solid bodies through which light can pass, it is refracted by them, and by different bodies in different degrees.

If when the vessel  $wxyz$  is empty we place at  $c$  any

bright object, such as a shilling, and place the eye at A, in the straight line  $Ahc$ , the shilling will be distinctly seen, because the light which proceeds from it must enter the eye at A. If we now pour water into the vessel till it rises to  $tr$ , without altering the position of the shilling, then the eye at A will no longer see the shilling, but if we move the shilling from  $c$  to  $D$ , it becomes visible to the eye at A the instant it comes to  $D$ . Now as the light from the shilling at  $D$  must pass to the eye in a straight line after it comes out of the water, it must pass in the direction  $BhA$ , and therefore the ray of light from the shilling at  $D$ , by which it was seen at A, must have been  $DB$ , and this ray in passing out of the water must have been refracted at  $B$  into the line  $BhA$ . A similar effect will be produced if  $tr$  is the surface of salt water, alcohol, oil, or glass; but with these substances we must place the shilling beyond  $D$  towards  $z$ , so that it may be seen at A. Hence we are led to conclude that when a ray of light passing through a liquid or solid body in a slanting direction to its surface quits it, it is refracted by that body, and by different bodies in different degrees.

By the preceding simple experiments we are enabled to observe the nature of the refraction of light when passing from a rare or thin medium, such as air, into a denser medium, such as water, and also out of a dense medium or substance into a rare medium or substance.

*The Law of Refraction.*—Let a circle  $RTSU$  be described upon a piece of slate or metal, and having drawn the diameters  $RCS$ ,  $TCU$ , perpendicular to each other, let a small tube  $Ac$ , be attached to the plate, so that it can move freely round  $c$ . If we now put the plate  $RTSU$  in a vessel of water, and fix it in such a manner that the surface of the water will coincide with

the line  $TV$ , but does not touch the lower end,  $c$ , of the tube  $Ac$ , and then move the tube  $Ac$  into the position  $Rc$ , and admit a ray of light down through the tube, we shall find that the ray, on entering the water at  $c$ , will pass on in the same straight line to the point  $s$ , showing clearly that a ray of light falling perpendicularly upon a refracting surface is not bent or refracted in its perpendicular direction. If the tube  $Ac$  be now placed in the position  $Ac$ , and a ray of light is caused

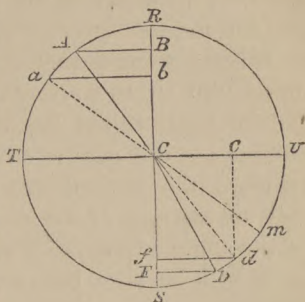


Fig. 2.

to pass through it, the ray will not pass on in a straight line, but will be bent or refracted at  $c$  into the line  $cd$ , and fall on the circle at  $d$ . The angle  $ACR$ , which the ray or tube makes with the perpendicular  $Rcs$  is called the *angle of incidence*; and the angle  $dcs$ , which the bent ray  $cd$  makes with the same perpendicular, is called the *angle of refraction*. If we now measure the length of the lines  $AB$  and  $df$ , the shortest distances from the points  $A$  and  $d$  to the perpendicular  $Rcs$ , by a scale of equal parts, or by a pair of compasses, we shall find that  $AB$  is very nearly one and one-third times the length of  $df$ ; or, more correctly,  $AB$  is to  $df$  as 1.336 to 1.

If this experiment be repeated when the tube  $Ac$  is in any other slanting direction, such as  $ac$ , in which case the bent ray will be  $cd$ , then if the lines  $ab$  and  $fd$  be measured as before, we shall find that as  $ab$  is to  $fd$  so is 1.336 to 1. The line  $AB$  is called the *sine of the angle of incidence*  $ACR$ , and  $df$  the *sine of the angle of*

refraction  $n c s$ . It therefore follows that from air into water the sine of the angle of incidence is to the sine of the angle of refraction as 1.336 to 1, whatever be the slanting direction of the incident ray with respect to the surface.

When the ray passes in a slanting direction through water into air the reverse rule holds good; that is, if  $dc$  be the incident ray through water on the aerial surface  $tu$ , it is bent at  $c$  in the direction  $ca$  in passing through the air. Hence it follows that from water into air the sine of the angle of incidence is to the sine of the angle of refraction as 1 to 1.336.

It will be seen by comparing the two foregoing cases that when the ray  $ac$  passes from air into water, the ray  $cd$  is refracted *towards* the perpendicular  $cs$ , and the sine of the angle of incidence is 1.336, while the sine of the angle of refraction is 1; but when the ray  $dc$  passes from water into air, the ray  $ca$  is refracted *from* the perpendicular  $cr$ , and the sine of the angle of incidence is 1, while the sine of the angle of refraction is 1.336.

By these means we are enabled to determine the direction of any ray after it is refracted by the surface of water. If we want to find the direction of the ray  $ac$  (Fig. 2) for example, when it is refracted after falling on the surface  $tu$  of water at the point  $c$ . Draw  $cr$  perpendicular to  $tu$ , and from  $a$  draw  $ab$  perpendicular to  $cr$ , measure  $ab$  by any scale of equal parts, then say as 1.336 is to 1, so is the length of  $ab$  as measured by the scale to the length required. This proportion gives the length by the scale of the sine of the angle of refraction. If the length of this line be laid off from  $c$  to  $e$ , towards  $u$ , and a line be drawn through  $e$  parallel to  $cs$  till it meet the circumference

of the circle at  $d$ , a line then drawn from  $c$  to  $d$  determines the direction of the refracted ray, and  $df$  perpendicular to  $cs$  is the sine of the angle of refraction  $dcs$ .

The number 1.336 is called the index, or exponent, or co-efficient of the refraction of water, and sometimes its refractive power.

If similar experiments to the foregoing were made with other fluids and solids we should find that the law of refraction governs all of them, and that the index of refraction varies in each.

Why light is thus refracted in passing from one substance or medium into another is still unknown, although attempts to explain the cause of it have been made by Descartes, Fermat, Liebnitz, and other eminently scientific men.

The following table contains the indices of refraction for several bodies, by means of which we can trace the passage of a ray through these bodies.

I. TABLE OF INDICES OF REFRACTION.

	Index of Refraction.		Index of Refraction.
Chromate of lead (max.)	2.974	Carbonate of lead (min.)	1.813
" (min.)	2.500	Calomel . . . . .	1.970
Ruby silver . . . . .	2.564	Zircon (max.) . . . . .	2.015
Realgar, artificial . . . . .	2.549	" (ord.) . . . . .	1.961
Octohedrite . . . . .	2.500	Glass, lead 2, sand 1 . . . . .	1.987
Diamond, Rochon . . . . .	2.755	" flint 1 . . . . .	1.830
Diamond, Newton . . . . .	2.439	Sulphate of lead . . . . .	1.925
Nitrate of lead . . . . .	2.322	Garnet . . . . .	1.815
Blende . . . . .	2.260	Spinnelle, ruby . . . . .	1.812
Phosphorus . . . . .	2.224	Spinnelle, Brewster . . . . .	1.764
Glass of antimony . . . . .	2.200	Arsenic . . . . .	1.811
Sulphur, melted . . . . .	2.148	Sapphire, blue . . . . .	1.794
" native (max.) . . . . .	2.115	" white . . . . .	1.768
" (min.) . . . . .	2.038	Pyrope . . . . .	1.792
Glass, lead 3, flint 1 . . . . .	2.028	Nitrate of silver (max.) . . . . .	1.788
Tungstate of lime (max.) . . . . .	2.129	" (min.) . . . . .	1.729
" (min.) . . . . .	1.970	Glass, lead 1, flint 1 . . . . .	1.787
Carbonate of lead (max.) . . . . .	2.084	Ruby . . . . .	1.779

	Index of Refraction.		Index of Refraction
Feldspar, spinelle . . .	1.764	Gum mastic . . .	1.560
Cinnamon stone . . .	1.759	Burgundy pitch . . .	1.560
* Glass, lead 3, flint 4 . . .	1.732	Resin . . .	1.559
"    "    1, "    2 . . .	1.724	Turpentine . . .	1.557
Axinite . . .	1.735	Rock salt . . .	1.557
Epidote (max.) . . .	1.703	Sugar, melted . . .	1.554
"    (min.) . . .	1.661	Gum thus . . .	1.554
Chrysoberyl . . .	1.760	Comptonite . . .	1.553
Nitrate of lead . . .	1.758	Chalcedony . . .	1.553
Carbonate of strontian		Sulphate of copper (max.)	1.552
(max.) . . .	1.700	(min.) . . .	1.531
(min.) . . .	1.543	Copal . . .	1.549
Boracite . . .	1.701	Canada balsam . . .	1.549
Sulphuret of carbon . . .	1.768	Amber . . .	1.547
Periodot (max.) . . .	1.685	Elemi . . .	1.547
(min.) . . .	1.660	Oil of tobacco . . .	1.547
Arragonite (ord.) . . .	1.693	Dichroite . . .	1.544
(ext.) . . .	1.535	Apophyllite . . .	1.543
Calcareous spar (ord.) . . .	1.654	Plate glass from 1.514 to	1.542
(ext.) . . .	1.483	Colophony . . .	1.543
Sulphate of barytes (ext.)	1.647	Beeswax . . .	1.542
(ord.) . . .	1.631	Olibanum . . .	1.544
Topaz, colourless (ext.) . . .	1.620	Carbonate of barytes (min.)	1.540
"    "    (ord.) . . .	1.610	Crown glass from 1.525 to	1.534
"    Brazil (ext.) . . .	1.640	Caoutchouc . . .	1.530
"    "    (ord.) . . .	1.632	Oil of sassafras . . .	1.534
Oil of cassia . . .	1.641	cloves . . .	1.535
Euclase (ext.) . . .	1.663	Balsam of Capivi . . .	1.528
(ord.) . . .	1.643	Leucite . . .	1.527
Mother-of-pearl . . .	1.653	Citric acid . . .	1.527
Balsam of tolu . . .	1.628	Shell lac . . .	1.525
Castor . . .	1.626	Sulphate of lime . . .	1.525
Muriate of ammonia . . .	1.625	Gum myrrh . . .	1.524
Anhydrite (ext.) . . .	1.622	Wavellite . . .	1.520
(ord.) . . .	1.577	Gum tragacanth . . .	1.520
Guaiacum . . .	1.619	Mesotype (max.) . . .	1.522
Flint glass from 1.625 to	1.590	(min.) . . .	1.516
Meionite . . .	1.606	Saltpetre (nitrate of pot-	
Oil of bitter almonds . . .	1.603	ash) . . . (max.)	1.514
"    anise seed . . .	1.601	(min.) . . .	1.335
Balsam of Peru . . .	1.597	Tartrate of potash and soda	1.515
Gum ammoniac . . .	1.592	Sulphate of zinc . . .	1.507
Tortoise shell . . .	1.591	"    potash . . .	1.509
Pitch . . .	1.586	Gum Arabic . . .	1.502
Balsam of styrax . . .	1.584	Stilbite . . .	1.508
Bottle glass . . .	1.582	Oil of cumin . . .	1.508
Horn . . .	1.565	"    pimento . . .	1.507
Quartz (ext.) . . .	1.558	"    sweet fennel seed .	1.506
(ord.) . . .	1.548	"    amber . . .	1.505
Mellite (ext.) . . .	1.556	"    rhodium . . .	1.500
(ord.) . . .	1.538	"    beech nut . . .	1.500

	Index of Refraction.		Index of Refraction.
Oil of nutmeg . . . . .	1·497	Oil of poppy . . . . .	1·463
Balsam of sulphur . . . . .	1·497	„ camomile . . . . .	1·457
Sulphate of iron (max.) . . . . .	1·494	Alum . . . . .	1·457
Oil of angelica . . . . .	1·493	Oil of wormwood . . . . .	1·453
„ carraway seed . . . . .	1·491	Spermaceti, melted . . . . .	1·446
Castor oil . . . . .	1·496	Fluor spar . . . . .	1·434
Tallow . . . . .	1·490	Sulphuric acid . . . . .	1·434
Obsidian . . . . .	1·488	Oil of rue . . . . .	1·433
Sulphate of magnesia		Phosphoric acid, fluid . . . . .	1·426
from 1·465 to 1·488		Nitric acid . . . . .	1·410
Oil of hyssop . . . . .	1·487	Muriatic acid . . . . .	1·410
Camphor . . . . .	1·487	Nitrous acid . . . . .	1·396
Cajeput oil . . . . .	1·483	Acetic acid . . . . .	1·396
Oil of almonds . . . . .	1·483	Malic acid . . . . .	1·395
„ savine . . . . .	1·482	Alcohol . . . . .	1·372
„ pennyroyal . . . . .	1·482	Oil of ambergris . . . . .	1·361
Carbonate of potash . . . . .	1·482	White of an egg . . . . .	1·361
Oil of spearmint . . . . .	1·481	Ether . . . . .	1·358
Gpal . . . . .	1·480	Cryolite . . . . .	1·349
Oil of thyme . . . . .	1·477	Salt water . . . . .	1·343
„ dill seed . . . . .	1·477	Aqueous humour of eye . . . . .	1·337
Essence of lemon . . . . .	1·476	Vitreous „ . . . . .	1·339
Oil of turpentine . . . . .	1·475	External coating of the	
„ rape seed . . . . .	1·475	crystalline . . . . .	1·377
„ juniper . . . . .	1·473	Middle coating „ . . . . .	1·379
„ bergamot . . . . .	1·471	Central coating „ . . . . .	1·299
„ olives . . . . .	1·470	Entire crystalline . . . . .	1·284
„ spermaceti . . . . .	1·470	Ice . . . . .	1·308
Fluellite . . . . .	1·470	Tabasheer . . . . .	1·111
Oil of lavender . . . . .	1·462	Air . . . . .	1·000294

TABLE OF THE REFRACTIVE POWERS OF GASES.

Vapour of sulphuret of		Carbonic acid . . . . .	1·000449
carbon . . . . .	1·001530	Carburetted hydrogen . . . . .	1·000443
Phosgene . . . . .	1·001159	Ammonia . . . . .	1·000385
Cyanogen . . . . .	1·000834	Carbonic oxide . . . . .	1·000340
Chlorine . . . . .	1·000772	Nitrous gas . . . . .	1·000303
Olefiant gas . . . . .	1·000678	Azote . . . . .	1·000300
Sulphurous acid . . . . .	1·000665	Atmospheric air . . . . .	1·000294
Sulphuretted hydrogen . . . . .	1·000644	Oxygen . . . . .	1·000272
Nitrous oxide . . . . .	1·000503	Hydrogen . . . . .	1·000138
Hydrocyanic acid . . . . .	1·000451	Vacuum . . . . .	1·000000
Muriatic acid . . . . .	1·000449		

TABLE II.

TABLE OF THE ABSOLUTE REFRACTIVE POWERS OF BODIES.

Tabasheer . . . . .	0·0976	Oxygen . . . . .	0·3799
Cryolite . . . . .	0·2742	Sulphate of barytes . . . . .	0·3829
Fluor spar . . . . .	0·3426	Sulphurous acid gas . . . . .	0·4455

	Index of Refraction.		Index of Refraction.
Nitrous gas . . . . .	0·4491	Cyanogen . . . . .	0·8021
Air . . . . .	0·4528	Sulphuretted hydrogen .	0·8419
Carbonic acid . . . . .	0·4537	Vapour of sulphuret of	
Azote . . . . .	0·4734	carbon . . . . .	0·8743
Chlorine . . . . .	0·4813	Ammonia . . . . .	1·0032
Nitrous oxide . . . . .	0·5078	Alcohol, rectified . . .	1·0121
Phosgene . . . . .	0·5188	Camphor . . . . .	1·2551
Selenite . . . . .	0·5386	Olive oil . . . . .	1·2607
Carbonic oxide . . . . .	0·5387	Amber . . . . .	1·3654
Quartz . . . . .	0·5415	Octohedrite . . . . .	1·3816
Glass . . . . .	0·5436	Sulphuret of carbon . .	1·4200
Muriatic acid . . . . .	0·5514	Diamond . . . . .	1·4566
Sulphuric acid . . . . .	0·6124	Realgar . . . . .	1·6669
Calcareous spar . . . . .	0·6424	Ambergris . . . . .	1·7000
Alum . . . . .	0·6570	Oil of cassia . . . . .	1·7634
Borax . . . . .	0·6716	Sulphur . . . . .	2·2000
Nitre . . . . .	0·7079	Phosphorus . . . . .	2·8857
Rain water . . . . .	0·7845	Hydrogen . . . . .	3·0953
Flint glass . . . . .	0·7986		

The indices of refraction given in Table No. I., relate to rays of light passing from a vacuum into the several bodies indicated. If it be required to find the index for a ray passing from one medium to another, it is only necessary to divide the index of the medium into which the ray is supposed to pass, by the index of the medium from which it passes, and the quotient will be the required index.

As the several media contained in this table are of different specific gravities, the indices of refraction annexed to their names do not show the relation of their absolute refractive powers, or the refractive powers of their ultimate particles. Hydrogen, for example, has a small index of refraction, which arises from its particles being at such a distance from one another; but if we consider its specific gravity, we shall find that, instead of having a less refractive index than most other bodies, its ultimate particles exceed most other bodies in their absolute action in refracting light.

By supposing that the ultimate particles of bodies are equally heavy, Sir Isaac Newton has shown that the absolute refractive power is equal to the excess of the square of the index of refraction above unity, divided by the specific gravity of the body. In this way Table II. has been calculated. If  $n^2 - 1$  express the square of the index of refraction above unity, and  $G$  express the specific gravity of a medium, and  $A$  represent its absolute refracting power, we shall have—

$$A = \frac{n^2 - 1}{G}.$$

When an elastic fluid or gaseous medium undergoes a change of density, its refracting power undergoes a corresponding change, increasing or decreasing as the density increases or decreases; but the *absolute refracting power* remains sensibly constant, the index of refraction varying in such a manner that  $n^2 - 1$  increases or diminishes in the same proportion as the density.

Euler observed that spirituous liquors have a greater refractive power in proportion to their strength. He found that when a single object-glass was held in boiling water till it had acquired the same degree of heat, its focal distance was 16 inches; whereas, when it was cold, it was  $16\frac{1}{4}$  inches; an increase of  $66^\circ$  Reaumur having made a difference of  $\frac{1}{4}$  of an inch in the focal distance of the lens. He also found that heat increases the refractive power of water and of other fluids, as well as that of glass.

## CHAPTER III.

## REFRACTION OF RAYS BY PRISMS AND LENSES.

WE are enabled by means of the law of refraction, already explained, to trace the course of a ray of light through any medium or body of any figure, or through any number of bodies, provided we can find the inclination of the incident ray to that part of the surface where the ray either enters or quits the body.

The substance commonly used for refracting the rays of light, both in optical experiments and in the construction of optical instruments, is glass. For these purposes it is shaped into solids, of the following forms, a section of each of which is shown in the annexed Fig. 3 :

1. A prism, shown at A, is a solid, having two plane surfaces—A P, A R—which are called its refracting sur-

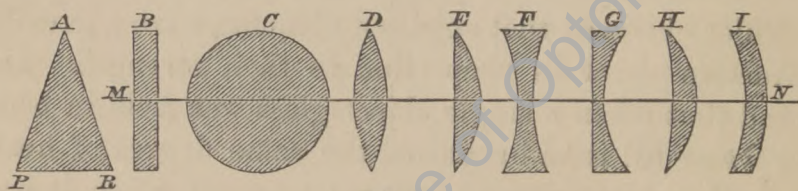


Fig. 3.

faces: The face P R, equally inclined to A P and A R, is called the base of the prism.

2. A plane glass, shown at B, has two plane surfaces, parallel to one another.

3. A spherical lens, shown at C, is a sphere, having every point in its surface equally distant from the common centre.

4. A double convex lens, shown at D, is a solid, bounded by two convex-spherical surfaces, whose centres are on opposite sides of the lens. When the radii

of its two surfaces are equal, it is said to be equally convex; and when the radii are unequal, it is said to be an unequally convex lens.

5. A plano-convex lens, shown at *e*, is bounded by a plane surface on one side, and by a convex surface on the other.

6. A double-concave lens, shown at *f*, is bounded by two concave surfaces, whose centres are on opposite sides of the lens.

7. A plano-concave lens, shown at *g*, is bounded by a plane surface on one side, and a concave surface on the other.

8. A meniscus, or new-moon-shaped lens, shown at *h*, has one side concave, and the other convex.

9. A concavo-convex lens, shown at *i*, is bounded by a concave surface on one side, and a convex surface on the other.

The axis of these lenses is a straight line, *m n*, in which the centres of the spherical surfaces are situated, and to which their plane surfaces are perpendicular. If the sections from *b* to *i* were to revolve round the line *m n*, they would generate the different solid lenses which they represent; but, in treating of the refraction of the lenses, we shall use the sections, because every section of the same lens passing through the axis *m n* has the same form, and hence what is true of one section must be true of the whole lens. The reader will bear in mind that the convex surface of a lens is like the outside of a watch-glass, and the concave surface like the hollow or inside of a watch-glass.

*Refraction through Prisms.*—As prisms are used in the construction of several optical instruments, and are essential parts of the apparatus employed for decomposing light and examining the properties of the com-

ponent parts of the solar beam, it is desirable that the reader should be able to trace the progress of light through their two refracting surfaces. Let  $ABC$  be a prism of plate glass, having its refracting power  $1.525$ , and let  $HR$  be a ray of light falling obliquely upon the

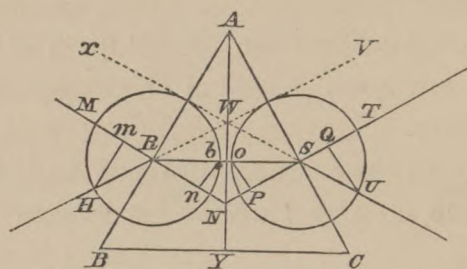


Fig. 4.

face  $AB$  at  $R$ . Through  $R$  draw  $MRN$  perpendicular to  $AB$ , and from any scale of equal parts take in a pair of compasses  $1.525$ , or  $15.25$  parts, and, setting one foot of the compasses on  $HR$ , move it along to some point  $H$  till the other foot falls only on one point  $m$  of  $MR$ ; then, with  $R$  as centre, and  $HR$  as radius, describe the circle  $Hmb$ . From the same scale take in the compasses  $1.000$  or  $10.00$ , and, setting one foot on the line  $RN$ , move it along to  $n$  till the other falls upon  $b$  in the circle  $Hmb$ , taking care that when one foot is placed at  $b$ , the other foot can touch  $RN$  in no other point but  $n$ . But  $Hm$  is the sine of the angle of incidence, and  $bn$  the sine of the angle of refraction; therefore the line  $Rbs$ , drawn through  $b$ , will be the refracted ray.

Again, as the ray  $Rbs$  meets the second refracting surface,  $AC$  at  $s$ , through  $s$ , draw  $NST$  perpendicular to  $AC$ , and from any scale of equal parts take in the compasses  $1.000$  or  $10.00$ , and, setting one foot on the line  $sb$ , move it along to some point  $o$ , till the other

falls only on one point of  $sN$ , as at  $P$ . In like manner take from the same scale  $1.525$  or  $15.25$ , and, setting one foot of the compasses in  $sT$ , move it towards some point  $Q$ , till the other foot falls at  $U$ , taking care that when one foot is placed at  $U$ , the other foot can touch  $sT$  in no other point but  $Q$ . But, as the ray is now passing out of glass into air,  $OP$  is the sine of the angle of incidence, and  $QU$  the sine of the angle of refraction; hence the line  $su$  drawn through  $U$  will be the refracted ray. The refraction of the prism has therefore bent the ray  $HR$ , which would have gone on to  $v$  in the straight line  $HRv$ , into the line  $su$ , which forms with  $Hv$  the angle  $Uwv$ , which is the deviation or change of direction of the ray; so that if the ray  $HR$  proceeded from the sun, or other luminous body, it would, by an eye placed at  $U$ , be seen at  $x$ , in the direction  $Uwx$ , and the angle of deviation will be  $Hwx$ , equal to  $Uwv$ .

In the preceding case the refracted ray  $RS$ , in passing through the prism, is parallel to its base  $BC$ ; and, this being the case, the angle of deviation  $Hwx$  is less than in any other position of  $RS$ , and therefore of  $HR$ , as may be readily proved by constructing the figure for any other position of these rays. If the eye be placed behind the prism at  $U$ , and the prism turned round, we shall find that  $RS$  is parallel to the base  $BC$ , by the *image* of the candle at  $x$  being stationary. When the prism is placed in the position that the ray  $RS$  is parallel to  $BC$ , or perpendicular to  $AY$ , a line bisecting the refracting angle  $BAC$  of the prism, then it is evident that the angle of refraction at the first surface,  $brn$ , is equal to  $BAy$ , half of the angle of the prism. Now, as half this angle is known, and the angle of incidence  $HRM$  can be easily measured, we

have, without further trouble, the angle of incidence and the corresponding angle of refraction at the surface  $AB$ .

By the following proportion we obtain the refractive power:—As the sine of the angle of refraction is to the sine of the angle of incidence, so is unity to the index of refraction—that is, dividing the sine of the angle of incidence by the sine of the angle of refraction we find the index. This is probably the simplest method, and the most generally applicable for measuring refractive powers or indices, because soft solids and fluids can be placed in the refracting angles of hollow prisms made by joining two plates of parallel glass.

*Refraction of Light through Plane Glasses.*—Let  $AB$  (Fig. 5) be a plane glass, and  $CD$  a ray of light refracted at  $D$ , on entering the glass in the direction  $DE$ , and at  $E$ , on going out of the glass, in the direction  $EF$ : if the direction of the refracted rays  $DE$  and  $EF$

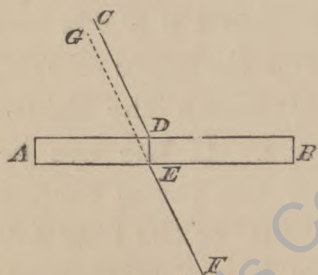


Fig. 5.

be determined by the method shown at Fig. 2, it will be found that  $EF$  is parallel to  $CD$ ; for, however much  $CD$  is bent out of its direction at the first surface of the glass, it is bent just as much in the opposite direction at the second surface, and will appear to an eye placed at

$F$ , as if it came in the direction  $GE$ , which is parallel to  $CD$ . If we suppose any number of rays to fall upon the upper surface of the glass  $AB$ , in a direction parallel to  $CD$ , they will suffer the same refraction as  $DE$ , and pass out at the lower side in a direction parallel to  $EF$ . Hence parallel rays falling on a plane

glass will retain their parallelism after passing through it.

If from any point  $c$  (Fig. 6) diverging rays, such as  $cd$ ,  $ce$ , be incident upon a plane glass  $AB$ , they will be refracted into the directions  $df$ ,  $eg$ , by the first surface, and in the directions  $fh$ ,  $gi$ , by the second. By continuing  $fd$  and  $ge$  backwards in the same straight lines, they will be found to meet at  $J$ , a point farther from the glass than  $c$ . If we suppose the surface  $ED$  to be that of standing water placed horizontally, an eye within it would see the point

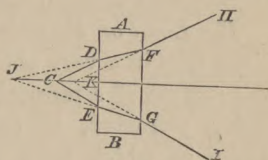


Fig. 6.

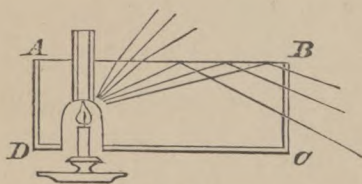
$c$  removed to  $J$ , the divergency of the rays  $df$ ,  $eg$  having been diminished by refraction at the surface  $ED$ . But when the rays  $df$ ,  $eg$ , undergo a second refraction, as in the case of plane glass, we shall find by continuing  $hf$ ,  $ig$  backwards in the same straight lines, that they will meet at a point  $K$ , and the object at  $c$  will appear to be brought nearer to the glass; the rays  $fh$ ,  $gi$ , by which it is seen, having been rendered more divergent by the two refractions. A plane glass, therefore, diminishes the distance from it of the divergent point of diverging rays.

If we suppose the rays  $hf$ ,  $gi$  to be converging to  $K$ , they will be made to converge to  $c$  by the refraction of the two surfaces, and consequently a plane glass causes the convergent point of converging rays to recede from it.

If the two surfaces  $DE$ ,  $FG$  are equally curved, the one being convex and the other concave, like a watch-glass, they will act upon light nearly as a plane glass, and precisely like a plane glass if the convex and

concave sides are so related that the rays  $DC$ ,  $FH$  are incident at equal angles on each surface; but this is not the case when the surfaces have the same centre, unless when the radiant point  $c$  is in their common centre. For these reasons glasses with parallel surfaces are used in windows and for watch glasses, as they produce very little change in the form and position of objects seen through them.

*The Limit of Possible Transmission.*—When a ray of light falls in a very oblique or slanting direction upon the surface of a refracting medium, the ray, instead of being refracted, is totally reflected. The incident angle at which total reflection commences varies in different bodies, and is called *the limit of possible transmission*. The properties here described may be illustrated experimentally.



[Fig. 7.]

Let  $ABCD$  (Fig. 7) represent a glass vessel filled with water, or any other transparent liquid. In the bottom is fixed a glass receiver, open at the bottom, and a tube, such as a lamp-chimney, carried upwards and continued above the surface of the liquid. If the flame of a lamp or candle be placed in the receiver, as shown in the figure, rays from it penetrating the liquid and proceeding towards the surface  $AB$  will strike this surface with various obliquities. Rays which strike it under angles of incidence within the limits of transmission will proceed into the air above the surface of the liquid, while those which strike it at greater angles of incidence will be reflected, and will penetrate the side  $BC$  of the glass vessel. An eye placed outside  $BC$  will see the candle reflected on that part of the surface  $AB$  upon

which the rays strike at angles of incidence exceeding the limit of transmission, and an eye placed above the surface *AB* will see the flame in the direction of the refracted rays which strike the surface with obliquities within the limit of transmission.

TABLE III.

SHEWING THE LIMITS OF POSSIBLE TRANSMISSION, CORRESPONDING TO DIFFERENT TRANSPARENT BODIES.

Names of Media.	Index of Refraction.	Limit of Transmission.
Chromate of lead . . . .	2.926 . . . . .	19 59
Diamond . . . . .	2.470 . . . . .	23 53
Sulphur . . . . .	2.040 . . . . .	29 21
Zircon . . . . .	2.015 . . . . .	29 45
Garnet . . . . .	1.815 . . . . .	33 26
Felspar . . . . .	1.812 . . . . .	33 30
Sapphire . . . . .	1.768 . . . . .	34 27
Ruby . . . . .	1.779 . . . . .	34 12
Topaz . . . . .	1.610 . . . . .	38 24
Flint-glass . . . . .	1.600 . . . . .	38 41
Crown-glass . . . . .	1.530 . . . . .	40 43
Quartz . . . . .	1.548 . . . . .	40 13
Alum . . . . .	1.457 . . . . .	43 21
Water . . . . .	1.336 . . . . .	48 28

By this table it appears that the limit of possible transmission increases as the index of refraction or refracting power diminishes. In the diamond, with an index of refraction of 2.470, we find the angular limit of possible transmission to be 23 degrees 53 minutes; whilst in water, with an index of refraction of 1.336, the angular limit of possible transmission is 48 degrees 28 minutes.

*Refraction through several Parallel Media.*—If parallel rays, after passing through a succession of media bounded by parallel surfaces, be incident upon the surface of a less refracting medium at an angle greater than the limit of transmission, they will be reflected, and, after reflection, will return through the several media, making angles with the other surfaces equal to

those which the rays made in passing through them, but on the other side of the perpendicular.

For example, let  $AB$  (Fig. 8) be a ray of light refracted successively at the surfaces of the media  $M M' M''$ ,

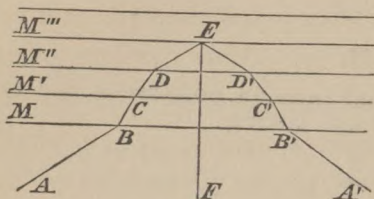


Fig. 8.

in the directions  $BC$ ,  $CD$ , and  $DE$ , and let it be supposed that the medium  $M'''$  having a less refracting power than the medium  $M''$ , the ray  $DE$  is incident upon its surface at an angle greater than the angle of transmission. This ray will consequently be reflected in the direction  $ED'$ , making an angle with a perpendicular at the point  $E$  equal to that which  $DE$  makes with it. The rays  $ED$  and  $ED'$  being equally inclined to the surface separating the media  $M''$  and  $M'$ , the ray  $ED'$  will be refracted by the medium  $M'$  in the direction  $D'C'$ , inclined at the same angle as  $DC$  to the surface  $DD'$ , but on the other side of the perpendicular  $EF$ ; and in the same way, in passing through the medium  $M$ , it will take a direction  $C'B'$  inclined to the surface  $CC'$  at the same angle as the ray  $CB$  is inclined to it, and finally will issue from the medium  $M$  in the direction  $B'A'$ , inclined to the surface  $BB'$  at the same angle as the incident ray  $AB$  is inclined to that surface. Therefore, if an eye were placed at  $A'$ , it would see the object from which the ray  $AB$  proceeds in the direction  $A'B'$ .

Several atmospheric phenomena of a wonderful character, such as mirage, fatamorgana, &c., may be explained by the principle above illustrated.

*Refraction of Light through Curved Surfaces.*—Hitherto we have only spoken of the refraction of light by plane surfaces, yet nearly all the refractions we have to con-

sider in optics take place at spherical or other curved surfaces. This circumstance, however, does not add any difficulty to the subject, for the refraction that takes place at a curved surface of any kind is precisely the same as at a plane surface which touches the curve at the point on which the ray falls. The surface of a lake perfectly still is a curved surface of the same radius as the earth, or about 4,000 miles, yet no skill could discover this curvature, or prove its existence in a square foot of the lake, although this square foot is larger in relation to the radius of the earth than the superficial space occupied by a ray of light is in relation to the radius of a common lens. It has been demonstrated by mathematicians that a line or plane touching a curve at any point may be regarded as coinciding with an infinitely small part of the curve; so that when a ray of light  $AB$  (Fig. 9) falls upon a curved refracting surface at  $B$ , its angle of incidence must be considered as  $ABD$ , the angle formed by the ray  $AB$  with the line  $DC$  passing to the centre, and perpendicular to the line  $TN$ , which touches, or is a tangent to, the curved surface at  $B$ . In small

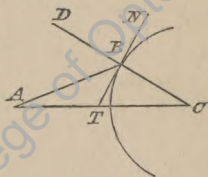


Fig. 9.

spherical surfaces, such as those of lenses generally are, the tangent  $TN$  is perpendicular to the radius  $CB$  of the surface. Hence in spherical surfaces the consideration of the tangent is not necessary; because the line  $CD$  drawn from the centre  $C$ , through the point of incidence  $B$ , is the perpendicular from which the angle of incidence is to be reckoned.

*Refraction of Light through Spheres.*—Let a ray of light  $ac$  (Fig. 10) fall upon a sphere of glass  $MN$ , at the point  $c$ , and parallel to  $GH$  or  $OI$ , the axis of the

sphere. Through  $c$  draw  $ocD$ , which is perpendicular to the surface of the sphere  $MN$  at  $c$ . By the same process which has been already explained for the prism (Fig. 4, p. 20), find the direction of the refracted ray  $cc'$ , and then find the direction of the refracted ray  $c'F$ , by the same process as before. Another ray  $BE$ ,

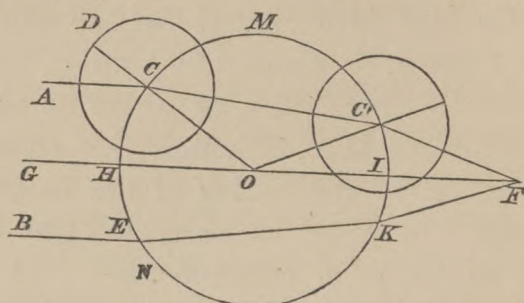


Fig. 10.

parallel to  $Ac$ , and falling on the sphere at  $E$ , as far from  $GH$  or  $I$ , the axis of the sphere, as  $c$  is, will evidently be refracted to  $F$ , because the circumstances of the two rays are precisely the same. The point  $F$  where these rays meet is called the *focus of parallel rays*.

If by the preceding method we determine the focus  $F$ , upon the supposition that the sphere is tabasheer, water, glass, and zircon, respectively, we shall, by measuring  $IF$ , the distance of the focus behind the sphere, obtain the following results, the radius  $oc$  of the sphere being one inch.

	Index of Refraction.	Distance $IF$ of the focus from the sphere.
		ft. in.
Tabasheer . . . . .	1.111	4 0
Water . . . . .	1.336	1 0
Glass . . . . .	1.500	0 0 $\frac{1}{2}$
Zircon . . . . .	2.000	0 0

When the index of refraction is greater than 2.000, as in diamond and many other substances, the ray of light  $cc'$  will cross the axis at a point somewhere between  $o$  and  $I$ , under which circumstance the ray will

suffer total reflexion at  $c'$ , towards another part of the sphere, where it will be again reflected, being conveyed round the circumference of the sphere, without being able to make its escape till it is finally lost by absorption. As this holds true of every section of a sphere, all rays, such as  $cc'$ , incident upon it in a circle equidistant from the axis  $GHOI$  will undergo similar reflexions.

*Rule for finding the Focus F of a Sphere.*—Divide the index of refraction by twice its excess above 1, and the quotient is the distance  $OF$ , which in glass is  $1\frac{1}{2}$  times the length of the radius of the sphere.

If diverging rays fall upon the points  $CE$  of the sphere, it is clear, from the inspection of the figure, that their focus will be on some point of the axis  $GHOI$  farther from the sphere than  $F$ , the distance of their focus increasing as the radiant point from which they diverge approaches to the sphere. When the radiant point is as far before the sphere as  $F$  is behind it, the rays will then be refracted in parallel directions, and the focus will be infinitely distant. If we suppose the rays  $FC$ ,  $FK$  to diverge from  $F$ , then they will issue after refraction in the parallel directions  $CA$ ,  $EB$ .

If converging rays fall upon the points  $CE$ , it is equally evident that their focus will be at some point of the axis nearer the sphere than  $F$ ; and their convergency may be so great that their focus may fall within the sphere. All these truths may be deeply impressed on the mind, by tracing rays of various degrees of divergency and convergency through the sphere, by the methods so fully explained in the case of the refraction through a prism.

*Refraction through Convex Lenses.*—Rays of light are refracted through a convex lens in the same manner as

through a sphere, and the course of the refracted rays may be found by the method already described for a prism and a sphere. Let  $LL$  (Fig. 11) be a double convex lens, whose axis is  $Rcf$ , and  $c$  its middle point, then parallel rays, such as  $RL$ ,  $R'L$ ,  $R''L$ , will be refracted

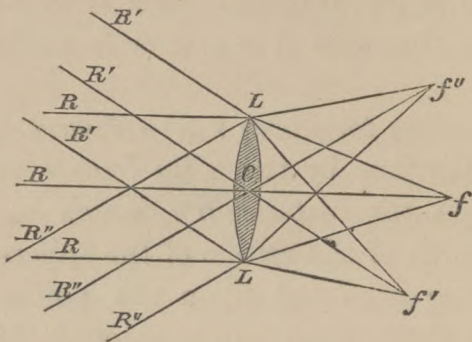


Fig. 11.

by the two surfaces as to meet at  $f$ , which is called the *principal focus of the lens*. It will also be found that parallel rays,  $R'L$ ,  $R'c$ ,  $R''L$ , and  $R''c$ , falling obliquely on the lens, will have their foci at  $f'$  and  $f''$ , at the same distance behind the lens. The oblique rays  $R'c$ ,  $R''c$ , which pass through the middle ( $c$ ) of the lens, will undergo refraction at each surface, but as the two refractions are equal and in opposite directions, the finally refracted rays  $cf'$ ,  $cf''$  will be parallel to  $R'c$ ,  $R''c$  respectively. Therefore, in considering the oblique rays, such as  $R'L$ ,  $R''L$ , we may regard the lines  $R'f$ ,  $R''f$ , passing the middle of the lens, as the directions of the rays corresponding to  $R'c$ ,  $R''c$ . The distance  $cf$  is called the focal distance of the lens, and may be found by the following rule, when the thickness of the lens is so small that it may be neglected.

*Rule for finding the Principal Focus, or the Focus of Parallel Rays, for a Glass Lens unequally Convex.*—Multiply the radius of one surface by the radius of the other,

and divide twice the product by the sum of the same radii.

When the lens is equally convex, the focal distance will be equal to the radius.

*Rule for finding the Principal Focus of a Plano-convex Lens* (as E, Fig. 3) *of Glass*.—When the convex side is exposed to parallel rays, the focal distance will be equal to twice the radius of its convex surface, diminished by two-thirds of the thickness of the lens.

When parallel rays fall upon the plane side, the focal distance will be equal to twice the radius.

*Converging Rays*.—When converging rays, or rays which proceed to one point, such as RL, RL (Fig. 12), are intercepted by, or fall upon, a convex lens LL, they will be refracted so as to converge to a point or focus  $f$ , nearer the lens than its principal focus  $o$ . As the point of convergence  $F$  recedes from the lens, the point

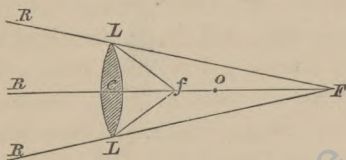


Fig. 12.

$f$  also recedes from it towards  $o$ , beyond which it never goes; and as  $r$  approaches the lens,  $f$  also approaches to it. The points  $F$  and  $f$  are called conjugate foci, because the place of one varies with the place of the other, and, though every lens has but one principal focus, yet its conjugate foci are innumerable.

*Rule for finding the Focus of Converging Rays when the Lens is unequally Convex*.—Multiply twice the product of the radii of the two surfaces of the lens by the distance  $Fc$  of the point of convergence, for a dividend. Mul-

multiply the sum of the two radii by the same distance  $Fc$ , and to this product add twice the product of the radii, for a divisor. Divide the dividend by the divisor, and the quotient will be the focal distance,  $cf$ , required.

If the lens is equally convex, multiply the distance  $Fc$  by the radius of the surface, and divide that product by the sum of the same distance and the radius, and the quotient will be the focal length,  $fc$ , required.

*Rule for finding the Focus of Converging Rays when the Lens is Plano-convex.*—Divide twice the product of the distance  $Fc$ , multiplied by the radius, by the sum of that distance and twice the radius, and the quotient will be the focal distance,  $fc$ , required.

*Diverging Rays.*—When diverging rays, or rays which proceed from one point, such as  $F$  (Fig. 13), fall upon a convex lens  $LL$ , whose principal focus is  $o$ , the refrac-

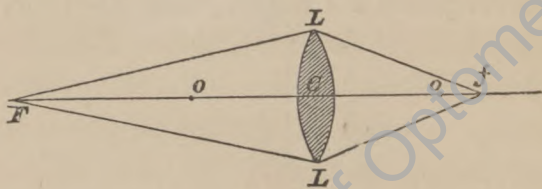


Fig. 13.

tion of the lens will cause them to converge to a focus  $f$ , beyond  $o$ . As the point  $F$  recedes from the lens, the focus  $f$  will approach to it, and when  $F$  is infinitely distant, or when the rays are parallel,  $f$  will coincide with  $o$ . If  $F$  approaches to  $o$ , the focus  $f$  will recede from  $o$ ; and when  $F$  coincides with  $o$ ,  $f$  will be infinitely distant, or the refracted rays will be parallel. When  $F$  is between  $o$  and  $c$ , the refracted rays will diverge. The points  $F$  and  $f$  are called conjugate foci, as in the case of converging rays.

*Rule for finding the Focus of an unequally Convex Lens*

*for Diverging Rays.*—Multiply twice the product of the radii of the two surfaces of the lens by the distance,  $fc$ , of the point of divergence, for a dividend. Multiply the sum of the two radii by the same distance,  $fc$ , and from this product subtract twice the product of the radii, for a divisor. Divide the dividend by the divisor, and the quotient will be the focal distance,  $cf$ , required.

*Rule if the Lens is equally Convex.*—Multiply the distance of the point of divergence from the lens by the radius of the surfaces, and divide the product by the difference between the same distance and the radius, and the quotient will be the focal distance,  $cf$ , required.

*Rule when the Lens is Plano-Convex.*—Divide twice the product of the distance of the point of divergence, multiplied by the radius, by the difference between that distance and twice the radius, and the quotient will be the focal distance required.

*Refraction of Light through Concave Lenses.*—Light is refracted through concave lenses in the same manner as through prisms, and the direction of the refracted rays may, in all cases, be found by the method already described for the prism. (See Fig. 4.)

*Parallel Rays.*—Let  $LL$  (Fig. 14) be a doubly concave lens, and  $RL, RL$  parallel rays incident upon it; the rays will diverge after refraction in the directions  $Lr, Lr$ , as if they proceeded from a point,  $F$ , which is the principal focus; or, as it is sometimes called in such a case as the present, the virtual focus.

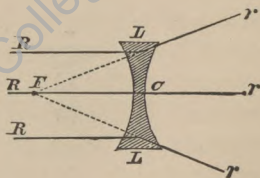


Fig. 14.

The rule for finding  $F$  is the same as for the convex

*Converging Rays.*—When converging rays proceeding to a point  $F$  (Fig. 15), beyond the principal focus,  $o$ , of a concave lens, fall upon it, they will be made to diverge

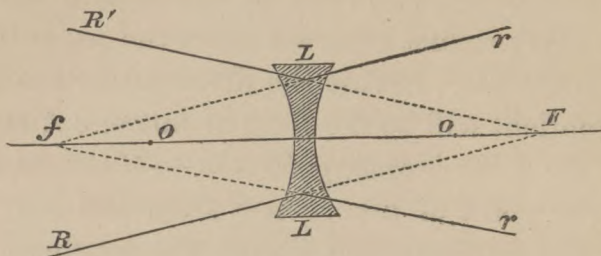


Fig. 15.

in lines  $Lr$ ,  $Lr$ , as if they proceeded from a focus  $f$ , in front of the lens beyond  $o$ . When  $F$  coincides with  $o$ , the refracted rays will be parallel; and when the point  $F$  is nearer the lens than  $o$ , the refracted rays will converge to a focus on the same side of the lens as  $F$ , but on the other side of  $o$ . The foci  $F$  and  $f$  are called conjugate foci, and when the position of either of them is given, the position of the other may be found by the rule for converging rays falling on a convex lens (Fig. 12).

*Diverging Rays.*—When diverging rays  $FL$ ,  $FL$  (Fig. 16), radiating from a point  $F$  without the focus  $o$ , fall

upon a concave lens  $LL$ , they will diverge in directions  $Lr$ ,  $Lr$ , as if they radiated from a point  $f$ , between  $o$  and  $c$ ; and as  $F$  approaches to  $c$ ,  $f$  will also approach to it; and the distances  $Fc$ ,  $fc$  will be

found when either of them is given, by the same rule as for diverging rays falling upon a convex lens. (See Fig. 13.)

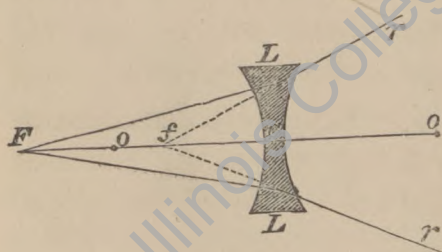


Fig. 16.

*Refraction of Light through a Meniscus, and Concavo-convex Lenses.*—The effect of a meniscus in refracting light is the same as a convex lens of the same focal distance; and that of a concavo-convex lens is the same as that of a convex lens of the same focal distance.

*Rule for a Meniscus with Parallel Rays.*—Divide twice the product of the two radii by their difference, and the quotient will be the focal distance required.

*Rule for a Meniscus with Converging Rays.*—Multiply twice the distance of the radiant point by the product of the two radii for a dividend. Multiply the difference between the two radii by the same distance of the radiant point, and to this product add twice the product of the radii for a divisor. Divide the above dividend by the divisor, and the quotient will be the focal distance required.

The same rule applies to diverging rays.

Both the foregoing rules apply to concavo-convex lenses; but the focus is a virtual one in front of the lens.

The reader would find it a great advantage to demonstrate to himself the truth of the preceding rules and observations by actually projecting or plotting the rays and lenses in large diagrams, and determining the course of the rays after refraction by the method shown in Figs. 4 and 10. He will thereby obtain a knowledge of the progress of light through refracting surfaces, which will very much facilitate the study of the following chapters.

## CHAPTER IV.

## FORMATION OF IMAGES BY LENSES.

If  $c$  (Fig. 17) be a small hole in the front of a box  $A B$   $m n$ , and  $M N$  an object before it, the rays from the end  $M$  will pass straight through the hole  $c$ , and illuminate the point  $m$  of the back of the box with their own

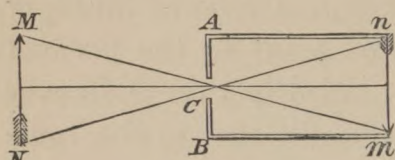


Fig. 17.

colour; the rays from  $N$  will do the same at  $n$ ; and all other points of  $M N$  will in like manner throw their rays on points directly opposite them between  $m$  and  $n$ .

The smaller the aperture  $c$  is made, the more distinct will be the picture,  $m n$ , of the object  $M N$ ; but the picture will be faint, as the hole  $c$  admits but a small number of the rays which emanate from every point of the object  $M N$ . If we enlarge the hole  $c$ , and substitute a lens  $L L$ , as in Fig. 18, having  $L n$  for the focal

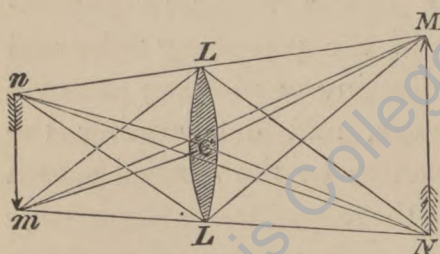


Fig. 18.

distance suited to the distance of the object  $M N$ , we shall have an image or picture,  $n m$ , every way similar to that formed by the hole, but brighter and more distinct. Since all the rays that flow from  $M$ ,

such as  $M L$ ,  $M L$ , and fall upon the lens  $L L$ , will be refracted to a focus at  $m$ , and all the rays from  $N$  to a focus at  $n$ , they will there paint a distinct picture of the points from which they come, and in like manner pictures of all intermediate points between  $M$  and  $N$  will be painted between  $m$  and  $n$ .

It is evident from Fig. 18 that the picture or image,  $m n$ , formed by a convex lens must be inverted, for it is impossible that rays from the upper end  $m$  of the object can be refracted to the upper end of the image at  $n$ .

The length of the image formed by a convex lens is to the length of the object as the distance of the image is to the distance of the object from the lens.

The relative positions of the object and image when the object is placed at various distances from the lens are exactly the same as the conjugate foci of diverging rays, as shown in Fig. 13, so that we can form an image of an object at any distance behind the lens we please, greater than its principal focus, and so make this image as large as we please, and in any proportion to the object. If we wish to have the image large we must bring the object near the lens, and if we wish to have it small we must remove the object farther from the lens; and these effects we can vary still more by using lenses of different focal distances.

The brightness of the image may be increased by increasing the size of the lens or the area of its surface. If a lens has a superficial area of 8 square inches, it will intercept twice as many rays proceeding from every point of an object as if its area were only 4 square inches, so that when it is impracticable to increase the brightness of the object by illuminating it, we may increase the brightness of the image by using a larger lens. There are, however, certain objections to the use of large lenses for photographic purposes, which are fully explained in a future chapter.

Hitherto we have supposed the image  $m n$  to be received on a smooth and white surface of paper, or other material, on which a picture of it is distinctly formed; but if we receive it upon ground glass, or upon a plate

of glass one of whose sides is coated with a dry film of skimmed milk, and if we place our eye 8 or 10 inches behind this semi-transparent ground interposed at  $m n$ , we shall see the inverted image,  $m n$ , as distinctly as before. If we keep the eye in this position, and remove the semi-transparent ground, we shall see an image in the air distinctly, and brighter than before. The cause of this will be readily understood when we consider that all the rays which form by their convergence the points  $m n$  of the image  $m n$ , cross one another at  $m n$ , and diverge from these points in the same manner as they would do from a real object of the same size and brightness placed at  $m n$ . The image  $m n$  may therefore be regarded as a new object; and by placing another lens behind it, another image of the image  $m n$  would be formed, exactly of the same size and in the same position as it would have been had  $m n$  been a real object. But since this secondary image of  $m n$  must be inverted as regards the first image, it will be erect in regard to the object  $m n$ , so that by using one or more lenses we can obtain inverted or direct images of any object at pleasure.

In order to explain how lenses increase or magnify objects, and make them appear as if they were brought nearer to us, the reader must understand what is meant by the apparent magnitude of objects. If an eye placed at  $E$  looks at a man,  $a b$  (Fig. 19), placed at a distance, his general outline only will be seen, and neither his age, nor features, nor his dress will be distinguished. When he is brought gradually nearer to us we discover the separate parts of his dress, till, at the distance of a few yards, we perceive his features; and when he is brought still nearer we can observe the finest lines in his skin. At the distance  $E b$  the man is seen under

the angle  $b E a$ , and at the distance  $E B$  he is seen under the greater angle  $B E A$  or  $b E A'$ , and his apparent magnitudes,  $a b$ ,  $A' b$ , are measured in those different posi-

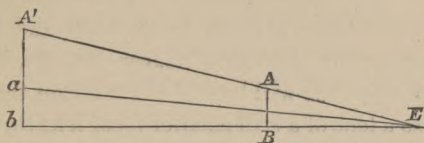


Fig. 19.

tions by the angles  $b E a$ ,  $B E A$ , or  $b E A'$ . The apparent magnitude of the smallest object may therefore be equal to the apparent magnitude of the greatest.

Let us now suppose the man  $a b$  to be placed at the distance of 100 feet from the eye at  $E$ , and that we place a convex glass of 25 feet focal distance half-way between the man  $a b$  and the eye, that is, 50 feet from each, then an inverted image of the man will be formed 50 feet behind the lens, and of the same size as the man, say 6 feet high. If this image is looked at by the eye placed 6 or 8 inches behind it, it will be seen quite distinct, and nearly as well as if the man had been brought from the distance of 100 feet to the distance of 8 inches from the eye, at which the details of his personal appearance can be examined. Now, in this case the man, though not actually magnified, has been apparently magnified, because his apparent magnitude has been increased in the proportion of 8 inches to 100 feet, or 150 times.

But if instead of a lens of 25 feet focal length we make use of a lens of a shorter focus, and place it in such a position between the eye and the man that its conjugate foci may be at the distance of 20 feet, and 80 feet from the lens, that is, that the man is 20 feet before

the lens, and the image 80 feet behind it, then the size of the image is four times that of the object, and the eye placed 8 inches behind this magnified image will see it with great distinctness. In this case the image is magnified 4 times directly by the lens, and 150 times by being brought 150 times nearer the eye, so that its apparent magnitude will be 600 times larger than before.

If we use a lens of a still smaller focal length, and place it in such a position between the eye and the man that its conjugate foci may be at the distance of 75 feet, and 25 feet from the lens, that is, that the man is 75 feet before the lens, and his image 25 feet behind it, then the size of the image will be only one-third of the size of the man; but though the image is thus diminished three times in size, yet its apparent magnitude is increased 150 times by being brought within 8 inches of the eye, so that it is still magnified, or its apparent magnitude is increased  $\frac{150}{3}$ , or 50 times.

At distances less than the preceding, where the focal length of the lens forms a considerable part of the whole distance, the rule for finding the magnifying power of a lens, when the eye views the image which it forms at the distance of say 6 inches, is as follows:—

*Rule for finding the Magnifying Power of a Lens.*—From the distance between the image and the object in feet subtract the focal distance of the lens in feet, and divide the remainder by the same focal distance. By this quotient divide twice the distance of the object in feet, and the new quotient will be the magnifying power, or the number of times that the apparent magnitude of the object is increased.

When the focal length of the lens is quite inconsiderable, compared with the distance of the object, as it generally is, the rule becomes this:—Divide the focal

length of the lens by the distance at which the eye looks at the image; or, as the eye will generally look at it at the distance of 6 inches, in order to see it most distinctly, divide the focal length by 6 inches; or, what is the same thing, double the focal length in feet, and the result will be the magnifying power.

Here we have the leading principle involved in the construction of the various kinds of telescopes, which will be more fully described in a future chapter.

*Distortion of Images.*—The pictures or images of objects produced by a lens are generally more or less distorted. If the object be a flat surface placed at right angles to the axis of the lens, that point of it which is in the axis will be nearer to the centre of the lens than any other point of it; and all other parts of the surface of the object will be so much the more distant from the centre of the lens as they are more distant from the point at which the axis meets the surface.

It has been already shown (Fig. 18) that the more distant an object is from the lens, the nearer to the lens will be its image; it follows, therefore, that in the case here supposed the images of those parts of the object which are farther from the axis of the lens will be nearer to the lens than are the images of those points of the object which are nearer to the axis of the lens.

It is evident from this, that when the object is flat its image must necessarily be curved, having its concavity towards the lens. But if the object, instead of being flat or straight, be curved, having its convexity towards the lens, then its image will be still more curved, since the extreme points will be relatively brought closer to the lens, so that the concavity of the one presented to the lens will be greater than the convexity of the other.

It will be understood, therefore, that when a real image of an object is formed by a convex, or by any equivalent converging lens, such image differs from the object, inasmuch as if the object be straight or flat, or if it be convex, the image will be concave towards the lens; and if the object be concave towards the lens, its image will be less concave, straight, or convex, according to the degree of curvature of the object. The curvature of the image, in photographic phraseology, is called the *curvature of the field*.

The curvature of the image is slightly affected by the thickness of the lens. The amount of distortion produced by this cause is called the *aberration of thickness*. Another species of distortion arises from the position of the lens with respect to the points situated obliquely to its axis; the two meridians of the lens, one vertical, the other horizontal, having different focal lengths. This distortion, or aberration, has been called *astigmatism*.

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## CHAPTER V.

### ON THE REFLEXION OF LIGHT.

THAT branch of optics which treats of the progress of rays of light after they are reflected from plane and curved surfaces, and of the formation of images from objects placed before such surfaces, is called catoptrics, from two Greek words, one of which signifies *from* or *against*, and the other *to see*, because objects are seen by light reflected *from* bodies.

When rays of light fall on the surface of an opaque body, they are arrested in their progress, such surfaces

not being penetrable by them. A certain part of them, more or less according to the quality of the surface and the nature of the body, is absorbed, and the remaining part is driven back into the medium from which the rays proceeded. This recoil of the rays from the surface on which they fall is called *reflexion*, and the light thus returning into the same medium from which it had come is said to be *reflected*.

Any substance of a regular form employed for the purpose of reflecting light, or of forming images of objects, is called a *speculum* or mirror. The substances generally used are metal and glass, highly polished on the reflecting surface. The name of mirror or looking-glass is commonly given to reflectors that are made of glass; and the glass is always coated with quicksilver on the back to make it reflect more light. The word *speculum* is applied to reflectors made of metal, or of alloys of metals, such as those made of silver, steel, or of grain tin mixed with copper.

Specula or mirrors are either *plane*, like a looking-glass, which is perfectly flat; *concave*, which is hollow, like the inside of a watch-glass; or *convex*, which is round, like the outside of a watch-glass.

As the light which falls upon glass mirrors is intercepted by the glass before it is reflected from the quicksilvered surface, we shall suppose all our mirrors to be formed of polished metal, as they are in nearly all optical instruments.

*The Law of Reflexion.*—When a ray of light,  $AB$  (Fig. 20), falls upon a plane speculum  $SM$ , at the point  $B$ , it will be reflected or driven back in a direction  $BC$ , which is as much in-

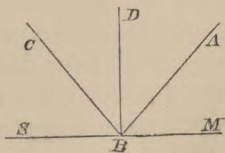


Fig. 20.

clined to  $DB$ , a line perpendicular to  $SM$ , as the ray  $AB$  was; that is, the angle  $CBD$  is equal to  $ABD$ . The ray  $AB$  is called the *incident ray*, and  $BC$  the *reflected ray*,  $ABD$  the *angle of incidence*, and  $DBC$  the *angle of reflexion*; and a plane passing through  $AB$  and  $BC$ , or the plane in which these two lines lie, is called the plane of incidence, or the plane of reflexion.

When the speculum is concave, as  $SM$  (Fig. 21), then

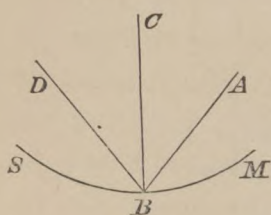


Fig. 21.

if  $c$  be the centre of the circle of which  $SM$  is a part, the incident ray  $AB$ , and the reflected ray  $BD$ , will form equal angles with the line  $BC$ , which is perpendicular to the small part of the speculum on which the ray falls at  $B$ . In this case also the

angle of incidence  $ABC$  is equal to the angle of reflexion  $CBD$ .

When the speculum is convex, as  $SM$  (Fig. 22), if  $c$

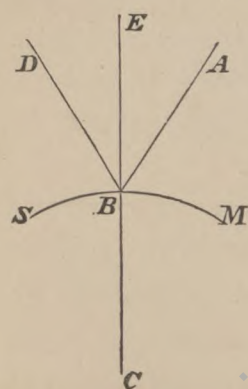


Fig. 22.

be the centre of the circle of which  $SM$  forms a part, and  $CE$  a line drawn through  $B$ , then the angle of incidence  $ABE$  will be equal to the angle of reflexion  $DBE$ .

These results may be proved experimentally by admitting a ray of sunlight through a hole in the window-shutter, and making it to fall on the mirror  $SM$  in the direction  $AB$ , when it will be seen reflected in the direction

$BC$  (Fig. 20), and  $BD$  (Figs. 21 and 22). If the incident ray is made to approach the perpendicular, the reflected ray will also approach it, and when the incident ray falls perpendicularly, it will be reflected back perpendicularly.

As these results are true under all circumstances, it

may be taken as a general law, that when light falls upon any polished surface, whether plane or curved, the angle of incidence is equal to the angle of reflexion.

*Reflexion of Light from Plane Mirrors.*—When parallel rays fall upon a plane mirror they will continue parallel after reflexion. If  $AC, A'C'$  (Fig. 23) are two parallel rays falling upon the plane mirror  $SM$ , they will be reflected into the parallel directions  $CB, C'B'$ ; since  $CD, C'D'$ , are both perpendicular to  $SM$ , they are parallel; and because  $AC$  is parallel to  $A'C'$ , and  $CD$  to  $C'D'$ , the angle  $ACD$  is equal to  $A'C'D'$ . Hence  $BCD$  is equal to  $B'C'D'$ , and  $CB$  parallel to  $C'B'$ . This principle may be easily proved experimentally.

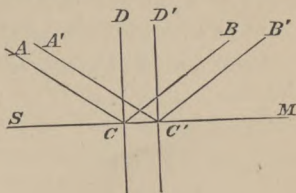


Fig. 23.

*Reflexion of Diverging Rays.*—When diverging rays fall upon a plane mirror, they will have the same divergency after reflexion.

If the rays  $AB, AC, AD$ , diverging from  $A$  (Fig. 24), fall upon the plane mirror  $SM$ , draw  $BE, CF, DG$ , so as to make the angle  $EBP$  equal  $ABP$ ;  $FCP'$  equal

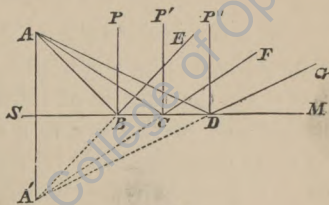


Fig. 24.

$ACP'$ , and  $GDP''$  equal  $ADP''$ ; then by continuing the lines  $EB, FC, GD$  backwards, they will be found to meet at  $A'$ , so that  $A'B, A'C, A'D$  are respectively equal to  $AB, AC, AD$ , and  $BAD$  equal  $B'A'D$ .

*Reflexion of Converging Rays.*—When converging rays fall upon a plane mirror, they will have the same convergency after reflexion. This is manifest

from Fig. 24, where the rays  $EB$ ,  $FC$ , and  $GD$  may be considered to fall on the mirror  $SM$ , and would have met in a point at  $A'$ , if the mirror had not intervened. Since the lines  $DA$ ,  $CA$ ,  $BA$  form angles with the perpendiculars at  $D$ ,  $C$ , and  $B$ , equal to the incident angles respectively, they will be the reflected rays which will meet at  $A$ , in the same manner as they would have done at  $A'$ , had there been no mirror to reflect them.

*Reflexion of Parallel Rays by Concave and Convex Mirrors.*—Let  $SM$  (Fig. 25) be a concave mirror, of

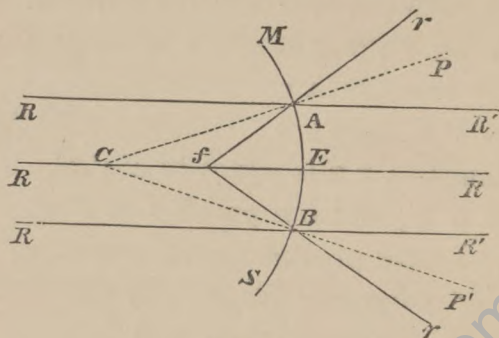


Fig. 25.

which  $RCE$  is the axis, or the line by a motion round which the section  $SM$  would generate a concave mirror. Let  $c$  be the centre of its concave surface  $SEM$ , and let parallel rays,  $RA$ ,  $RE$ ,  $RB$ , fall upon it at the points  $A$ ,  $E$ ,  $B$ ; these rays will be reflected or made to converge to a focus  $f$ , half-way between  $c$  and  $E$ ,\* so that the principal focal distance  $Ef$  is half the radius,  $cE$ , of the concave surface. The ray  $RE$  falling perpendicularly at  $E$ , will be reflected backwards in the same line  $ER$ , and will pass through  $f$ . In order to find the direction  $RA$  after reflexion, draw  $cAP$ , which will be perpendicular to the spherical surface at  $A$ ; then since

\* Provided the reflector have not greater breadth than  $5^\circ$  or  $6^\circ$  on each side of its vertex,  $E$ .

$\angle RAC$  is the angle of incidence, make  $\angle CAF$  equal to it, and  $Af$  will be the reflected ray; in like manner find  $Bf$ , the reflected ray for  $R B$ .

By continuing all the lines in the figure to the other side of the mirror, the very same reasoning may be used to prove that when parallel rays,  $R'A$ ,  $R'E$ ,  $R'B$ , fall upon a convex mirror, the reflected rays,  $Ar$ ,  $Er$ ,  $Br$ , will diverge as if they proceeded from  $f$ , which is called their *virtual focus*, and which is the *principal focus* of parallel rays.

*Reflexion of Diverging Rays by Concave and Convex Mirrors.*—Let  $SM$  (Fig. 26) be a concave mirror, whose

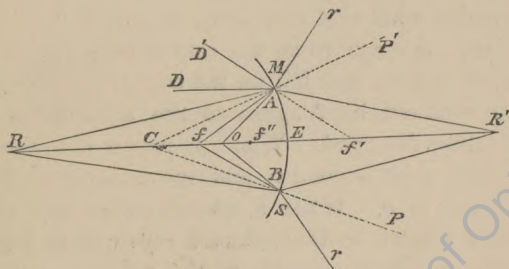


Fig. 26.

axis is  $CE$ , and centre  $C$ , and let  $o$  be its principal focus, or focus of parallel rays. Then if rays  $RA$ ,  $RE$ ,  $RB$ , diverging from  $R$ , fall upon it, they will be reflected to a focus  $f$  between  $o$  and  $C$ , so that  $Ro$  is to  $oC$  as  $of$  is to  $oC$ ; that is, the distance  $of$  is equal to half the radius multiplied by itself and divided by the distance of the divergent point  $R$  from the point  $o$ . Then by adding  $of$  to half the radius  $oE$ , we obtain  $fE$ , the conjugate focal length of the mirror for rays proceeding from  $R$ . This may be easily proved by projecting the reflected rays, and measuring the dis-

tances on a scale of equal parts; or it may be demonstrated geometrically in a very simple manner.

Let  $Ao$  be the reflected ray corresponding to the incident ray  $DA$ , parallel to the axis  $CE$ ; then since  $DAC$  is equal to  $CAO$ , and since  $RAC$  is equal to  $CAf$ , the remainder  $DAR$  is equal to the remainder  $OAf$ . But in the triangles  $ARO$ ,  $Afo$ , the angle  $AOf$  is common, and  $ARO$  equal to  $DAR$ , which is equal to  $fAo$ ; therefore the triangles are similar, and  $Ro$  is to  $OA$  as  $OA$  is to  $Of$ ; but  $OA$  is equal to  $OC$ , consequently  $Ro$  is to  $OC$  as  $OC$  is to  $Of$ .

Hence, when one of the conjugate foci  $R$  approaches to  $c$ , the other focus  $f$  also approaches to  $c$ ; and when  $R$  coincides with  $c$ ,  $f$  also coincides with it; so that when rays diverge from the centre of a sphere or a spherical surface, and fall on the concave surface, they are all reflected back again to the same point from which they diverged. When  $R$  passes  $c$  towards  $o$ ,  $f$  will then pass beyond  $c$ , and move farther off as  $R$  approaches to  $o$ . When  $R$  coincides with  $o$ ,  $f$  will be infinitely distant, or the reflected rays will be parallel. When  $R$  passes  $o$  towards  $E$ , the reflected rays will diverge like  $AD'$ , and will have their virtual focus about  $f'$  behind the mirror; and as  $R$  approaches  $E$ ,  $f'$  will also approach  $E$ .

If the lines  $CA$ ,  $CE$ ,  $CB$  be continued behind the mirror in Fig. 26, and if we suppose  $SM$  the surface of a *convex* mirror, upon which rays  $R'A$ ,  $R'E$ , and  $R'B$  fall, diverging from  $R'$ , then it may be proved, by the same system of reasoning, that they will be reflected in the directions  $Ar$ ,  $ER'$ ,  $Br$ , in lines which diverge from a virtual focus  $f''$ , whose distance from  $o$  or  $E$  is found by the rule above given for concave mirrors. As  $R'$  recedes from the mirror,  $f''$  will ap-

proach to  $o$ , with which it will coincide when  $R'$  is infinitely distant, and the rays become parallel. When  $R'$  approaches to  $E$ ,  $f''$  also approaches to  $E$ .

*Reflexion of Converging Rays by Concave and Convex Mirrors.*—It is manifest from Fig. 26 that all rays such as  $D'A$ , which fall converging upon the concave mirror  $SM$ , will be reflected to a focus  $f''$  between  $o$  and  $E$ , and this focus will approach to  $E$ , as the point of convergence  $f'$  approaches to  $E$ . It may be shown by the same reasoning as for diverging rays, that  $f' o$  is to  $o c$  as  $o c$  is to  $o f''$ ,  $f''$  being now between  $o$  and  $E$ .

When converging rays  $r A$ ,  $r B$  (Fig. 26) fall upon a convex mirror  $SM$ , as if they proceeded to some point  $f''$  between  $o$  and  $E$ , they will be reflected to  $R'$ , whose distance from  $o$  or  $E$  is found in the same manner as for diverging rays. From this it follows, and it may be proved also by projecting or plotting the rays, that when they converge to any point between  $o$  and  $c$ , they will be reflected as if they diverged from  $R$  beyond  $c$ . When they converge to  $c$ , they will be reflected in the same direction as if they came from  $c$ ; and if they converge to a point beyond  $c$ , they will be reflected diverging as if they proceeded from some point between  $c$  and  $o$ . When they converge to  $o$ , they will be reflected in parallel lines, or their focus will be infinitely distant; and if they converge to a point  $f''$  between  $o$  and  $E$ , they will be reflected to a real focus at  $R'$ , which will approach to  $E$  as  $f''$  approaches to  $E$ , according to the law already given.

## CHAPTER VI.

## FORMATION OF IMAGES BY PLANE, CONCAVE, AND CONVEX MIRRORS — REFLECTING TELESCOPES — REFLECTING MICROSCOPES.

THE principle of the formation of images by mirrors is the same as by lenses, and the place of the image may be found from the place of the object; and the radius of the mirror, by finding the foci or points of convergence of the rays, from the rules in the preceding chapter. We will now explain the application of these rules.

*Formation of Images by Plane Mirrors.*—Let  $s m$  (Fig. 27) be the surface of a plane mirror, and  $l n$  any

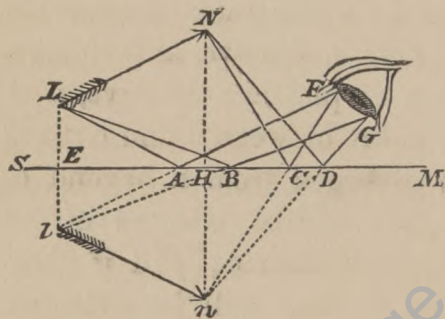


Fig. 27.

object placed before it; and let the eye of the observer be placed anywhere before the mirror as at  $F G$ . Of all the rays which proceed in every direction from the points  $l n$  of the object, and are reflected from the mirror, those which

enter the eye are comparatively few in number, and must be reflected from portions  $A B, C D$  of the mirror so situated, with respect to the eye and the object, that the angles of incidence of the rays which fall on these portions must be equal to the angles of reflexion of those which enter the eye between  $F$  and  $G$ . The ray  $l A$ , for example, will be reflected in the direction  $A F$ , and the ray  $l B$  in the direction  $B G$ ; in like manner, the ray  $n C, n D$  will be reflected in the directions  $C F$ ,

D G. Now the rays A F, B G, by which the point L is seen, enter the eye F G as if they came from  $l$ , as far behind the mirror as L is before it, and the rays C F, D G enter the eye as if they came from a point  $n$ , as far behind the mirror as N is before it,—that is,  $EL$  is equal to  $El$ , and  $HN$  to  $hn$ . Therefore, if we join  $ln$ , it will be of the same length as  $LN$ , and have the same position behind the mirror as the object has before it. If the eye F G is placed in any other position before the mirror, and if rays are drawn from L and N, which after reflexion enter the eye, it will be found that these, if continued backwards, will meet at the points  $l$  and  $n$ , and consequently, in every position of the eye the image will be seen in the same spot, and of the same size, at equal distances from the eye. If the object LN is a person looking into the mirror, he will see a perfect image of himself at  $ln$ , and hence we have an explanation of the properties of the looking-glass.

*Formation of Images by Convex Mirrors.*—Let s M (Fig. 28) be a convex mirror, whose centre is c, and LN any object placed before it; then, upon the same principles which have been explained for a plane mirror, it will be found that an image of it will be formed at  $ln$ , the points  $ln$  being ascertained by continuing back the reflected rays A F, B G till they meet at  $l$ , and O H, D I till they meet at  $n$ . By joining the points L  $l$  and N  $n$ , and continuing

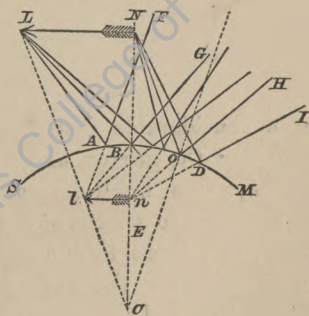


Fig. 28.

the lines till they meet, it will be found that they meet at the centre of the mirror  $c$ , whatever be the distance or the position of the object  $L N$ . The image  $l n$  is always less than the object; and as it must always be contained between lines  $L c$  and  $N c$ , which meet at  $c$ , its length  $l n$  will be to that of the object  $L N$  as  $c n$  is to  $c N$ . When  $L N$  approaches to the mirror,  $l n$  will also approach to it; and when  $L N$  touches the mirror,  $l n$  will also touch it, and become equal to  $L N$ . When  $L N$  recedes from the mirror,  $l n$  will become less and less, and recede from the mirror also; and when  $L N$  is infinitely distant,  $l n$  will be at  $E$ , the virtual focus of parallel rays. Objects, therefore, are always seen diminished in a convex mirror, unless when they touch it.

*Formation of Images by Concave Mirrors.*—Let  $s M$  (Fig. 29) be a concave mirror, and  $L N$  an object placed

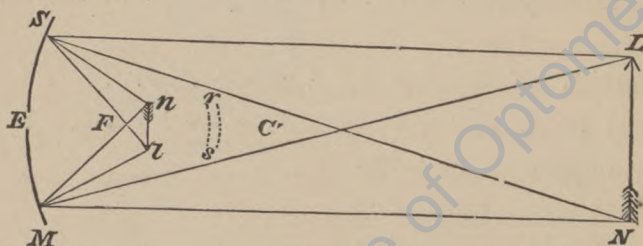


Fig. 29.

at a considerable distance from it, and let  $c$  be the centre of the mirror, and  $F$  its principal focus; then as the rays from  $L$  fall diverging on the mirror, they will be reflected to a focus at  $l$ , a little without its principal focus, and there form a representation of the point  $L$ ; in like manner the rays diverging from  $N$  will be reflected to  $n$ , and there form a picture of  $N$ ; so that there will be an inverted image,  $l n$ , of the object formed a little without the principal focus  $F$ . This image seems

to be suspended in the air, and has a very curious appearance when it is received on a thin blue smoke from a chafing-dish placed below  $l$ . As the object  $LN$  recedes from the mirror, the image  $ln$  approaches to  $F$ , with which it coincides when  $LN$  is infinitely distant, or the rays parallel.

This is the principle of the reflecting telescope. If we conceive  $ln$  to be a small object, then the rays diverging from it will form an enlarged image of it at  $LM$ , which may be viewed by the eye, or, which is better, by a convex lens, in which case it constitutes a reflecting microscope.

If the relative sizes of the object  $LN$  and its image  $ln$  be measured, it will be found that in every case the size of the image is to the size of the object as the distance of the image from the mirror is to the distance of the object from it.

If we consider the image  $ln$  as a new object, and place a small concave mirror,  $rs$ , behind it, so as to form an enlarged image of that image, the rays of which pass through a hole  $E$  in the large mirror  $SM$ , then this second or enlarged image may be viewed by the eye behind  $E$ , or magnified still more by a convex lens. In this case, the combination becomes the Gregorian reflecting telescope, called after its inventor, James Gregory. If we make the small mirror  $rs$  convex, and place it between  $F$  and  $ln$ , so as to intercept the rays before they actually meet their virtual foci  $ln$ , then an enlarged image of this virtual image will be formed somewhere about  $E$ , and may be magnified as before with a convex lens. In this case the arrangement forms the Cassegrainian reflecting telescope, after its inventor, M. Cassegrain. In these telescopes the magnifying power is determined in the same manner

as for convex lenses, or combinations of them; the size of the image being always to the size of its object as the distance of the image from the mirror is to the distance of the object.

When an object is placed nearer a concave mirror than its principal focus  $F$ , the rays will not have their focus in front of the mirror, but will diverge, as already shown, from conjugate foci behind the mirror, where they will form a correct representation of the object. The image is highly magnified when the object is near the focus, but it gradually diminishes as the object approaches the mirror, and it becomes equal to it when the object touches the mirror.

*Cylindrical Reflectors.*—A cylindrical mirror or reflector may be polished either on the concave or convex side. If a cylindrical mirror be placed vertically before an object, its effects upon the vertical dimensions will be the same as those of a plane looking-glass, and its effects upon the horizontal dimensions the same as those of a spherical mirror. If a cylindrical mirror be placed with its axis horizontal before a vertical object, it will have the same effect as a plane mirror on the horizontal dimensions, and as a spherical mirror on the vertical dimensions. The horizontal dimensions will, therefore, be preserved in the image, while the vertical dimensions will be enlarged, diminished, or reversed, in the same manner as would be the case with a spherical mirror.

*Conical Reflectors or Mirrors.*—A conical mirror, whether concave or convex, is circular in all sections made at right angles to its axis, and rectilineal in all sections made by planes through its axis. It will, therefore, if placed with its axis vertical, have the effect of an inclined-plane looking-glass on the vertical dimensions of an object, and will have the effect of a

spherical mirror on the horizontal dimensions; but each horizontal section will be differently magnified or diminished, according to the position of each section with reference to the axis of the cone, since the circular section of the cone will diminish in approaching the axis, and increase in receding from it. An infinite variety of amusing deceptions are thus produced.

## CHAPTER VII.

### ON SPHERICAL ABERRATION IN LENSES AND MIRRORS.

IN treating of the refraction of rays at the spherical surfaces of lenses, and the reflexion of rays at the spherical surfaces of mirrors, we have generally supposed that all the rays meet exactly in the focus. This, however, is not strictly true. The rules which have been given for determining the foci of spherical lenses and mirrors are true only for rays not extending more than ten degrees on each side of the axes.

In order to understand the cause of spherical aberration, let  $L m L$  (Fig. 30) be a plano-convex lens one of whose surfaces is spherical, and let its plane surface

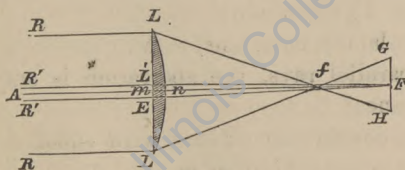


Fig. 30.

$L m L$  be turned towards parallel rays  $R L, R L$ . Let  $R' L, R' L$  be rays very near the axis  $A F$  of the lens, and let  $F$  be their focus after refraction. Let  $R L, R L$  be

parallel rays incident at the margin of the lens, and it will be found by projection that the corresponding refracted rays,  $Lf$ ,  $Lf$ , will meet at a point  $f$  nearer the lens than  $F$ . Intermediate rays between  $RL$  and  $R'L'$  will meet between  $f$  and  $F$ . Continue the rays  $Lf$ ,  $Lf$  till they meet a plane  $GH$  passing through  $F$ , and perpendicular to the axis. The distance  $fF$  is called the longitudinal spherical aberration, and  $GH$  the lateral spherical aberration. In a plano-convex lens like that in the figure, the longitudinal spherical aberration  $fF$  is no less than  $4\frac{1}{2}$  times  $mn$ , the thickness of the lens. It is quite clear that such a lens cannot form a distinct picture of any object in its focus  $F$ ; every object seen through such a lens, and every image formed by it, will be rendered confused and indistinct by spherical aberration.

By actually projecting the refracted rays for lenses of different kinds, which we recommend to the reader, he will be able to verify the following results for glass lenses:—

1. In a plano-convex lens, with its plane side turned to parallel rays as in Fig. 30, that is, to distant objects if it is to form an image behind it, or turned to the eye if it be used in magnifying a near object, the spherical aberration will be  $4\frac{1}{2}$  times the thickness of the lens, or  $4\frac{1}{2}$  times  $mn$ .

2. In a plano-convex lens, with its convex side turned towards parallel rays, the aberration is only  $1\frac{1}{10}$ th of its thickness.

3. In a double convex lens, with equal convexities, the aberration is  $1\frac{6}{10}$ th of its thickness.

4. In a double convex lens having its radii as 2 to 5, with its side whose radius is 5 turned towards parallel rays, the aberration will be the same as in a plano-convex lens, as in the first case; and if the side whose

radius is 2 be turned to parallel rays, the aberration will be the same as in the second case.

5. The lens which has the least spherical aberration is a double convex one, whose radii are as 1 to 6. When the face whose radius is 1 is turned towards parallel rays, the aberration is only  $1\frac{7}{100}$ th of its thickness; but when the side with the radius 6 is turned towards parallel rays, the aberration is  $3\frac{45}{100}$ ths of its thickness.

These results are equally true of plano-concave and double concave lenses.

If we call the aberration of the preceding lens 1, Sir John Herschel has shown that the following are the aberrations of other lenses :—

Best form, as in Case 5 . . . . .	1·000
Double convex or concave, with equal curvatures . . . . .	1·567
Plano-convex or concave, curved surface towards parallel rays . . . . .	1·081
Plano-convex or concave, plane surface towards parallel rays . . . . .	4·200

As the central parts of the lens LL (Fig. 30) refract the rays too little, and the marginal parts too much, it is evident that if the convexity be increased at  $n$ , and diminished gradually towards L, the spherical aberration would be removed. The ellipse and the hyperbola furnish us with curves of this kind, in which the curvature diminishes from  $n$  to L, and by which the spherical aberration may be entirely removed. There are, however, great practical difficulties to be overcome in the construction of lenses whose surfaces are elliptic or hyperbolic.

A meniscus with spherical surfaces has the property of refracting all converging rays to its focus, if its first surface be convex, provided the distance of the point of convergence or divergence from the centre of the first surface is to the radius of the first surface as the index of refraction is to unity.

Sir John Herschel has shown that if two plano-

convex lenses be used, and so placed that their convexities shall be turned towards each other, the plane side of one being turned towards the object, and that of the other towards the eye, their combined aberration will be only 0.248, or a fourth of that of a single lens in its best form, provided that the focal length of one be 2.3 times that of the other. When this combination is used for the object-glass of a telescope, the lens of less curvature must be turned to the object, and when used as a microscope it must be turned towards the eye.

If the two plano-convex lenses in this case have the same curvature, the spherical aberration will be 0.603 of the thickness of a single lens in its best form.

Sir John Herschel has also shown that the spherical aberration may be wholly effaced by combining a meniscus with a double convex lens, the latter being turned to the eye when it is used as a microscope, and to the object when it is to be used for forming images, or as a burning-glass.

The following are the radii and focal lengths of two combinations of these lenses, as computed by Sir John Herschel:—

	First combination.	Second combination.
Focal length of the double convex lens . . . . .	+ 10.000	+ 10.000
Radius of its first or outer surface . . . . .	+ 5.833	+ 5.833
Radius of its second surface . . . . .	— 35.000	— 35.000
Focal length of the meniscus . . . . .	+ 17.829	+ 5.497
Radius of its first surface . . . . .	+ 3.688	+ 2.054
Radius of its second surface . . . . .	+ 6.291	+ 8.128
Focal length of the compound lens . . . . .	+ 6.407	+ 3.474

From what has been already explained, it appears that the spherical aberration is increased with the curvature of the lens and the shortness of its focal length. Hence it follows that any contrivance by which a lens of a given focal length can be obtained with a less curvature will supply a means of diminishing the aberration.

tion without diminishing the power of the lens. But since the focal length of a lens is diminished as the index of refraction of the substance of which it consists is increased, it follows that if two lenses of the same focal length be constructed of different materials, that of which the material has the greater refracting power will have less convexity, and, therefore, less spherical aberration.

*Chromatic Aberration.*—The image of an object A (Fig. 30a), situated at a distance from a lens L, which is formed at its principal focus F, is deficient in sharpness, because it is there surrounded by a ring of violet light.

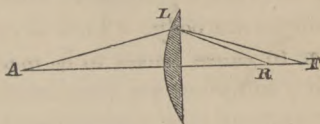


Fig. 30a.

At a point R, nearer the lens, the image is encircled by a red ring or aureola. This results from the fact that the object emits white light, which is composed of rays of different refrangibility. After refraction these rays are dispersed in different directions, and the violet rays being more refrangible than the red, have their focus at R, while the red rays have their focus at F. If we place a sensitised photographic surface at F, where the image appears the clearest, we shall obtain but a confused image, but if we advance the photographic surface to R, the focus of the violet rays, the image will be sharper and more distinct. This arises from the less refrangible rays having little or no influence on the various salts of silver ordinarily used for photographic surfaces, whilst the more refrangible rays, blue, indigo, and violet, are the most active. For this reason the bright focus of the lens at F, as judged of by the eye, is called the *visual focus*, whilst that determined by photographic

surfaces is called the *chemical focus*. These two foci in a photographic lens, or combination of lenses, should be coincident, else the lens, or combination of lenses, is said to have a chemical focus.

*Gem Lenses.*—One of the most obvious expedients, therefore, to diminish the effects of aberration is to find transparent media suitable for lenses whose refracting power is greater than that of glass. Several transparent substances having this important property are found among the precious stones. The diamond particularly has a greater refracting power than any known transparent body. This advantage induced scientific men to cause lenses to be made of diamond, sapphire, ruby, and other precious stones, and great hopes were entertained that vast improvements would result from their substitution for glass lenses. These hopes have, however, proved delusive, for, notwithstanding all that enterprise, skill, and perseverance could accomplish on the part of scientific men and practical opticians, the attempt has been abandoned on account of the heterogeneous nature of the gems, their double refraction, and the imperfect transparency and colour of some of them, and also on account of their cost.

*Aplanatic Lenses.*—Lenses, or combination lenses, which practically remove the effects of spherical aberration are said to be *aplanatic*, from two Greek words which signify *no straying*.

*Objects Invisible to the Naked Eye rendered Visible.*—Lenses and reflectors are capable of rendering objects visible which would be invisible to the naked eye, by increasing the quantity of light proceeding from them which enters the eye. The light which produces vision, as will be more fully explained in a future chapter, enters the eye through a circular aperture called the

pupil, which is the black circular spot surrounded by a coloured ring appearing in the centre of the front of the eye. When the eye receives the rays diverging from a distant object the number of rays which enter the pupil will be those included within a cone whose apex is the luminous point, and whose base is the pupil. None of the rays which fall outside that cone can enter the eye or contribute in any way to produce vision. But if a convex lens be interposed so as to receive a large cone of rays, and if the lens be capable of converging these rays to a focus at a short distance beyond it, the eye placed at or very near the focus will receive all the rays into the pupil. Putting aside, therefore, all consideration of the magnifying power of the lens, it will have the effect of increasing the quantity of light received by the eye from each point of the object in the proportion of the superficial area of the lens to that of the pupil; or what is the same, in the proportion of the square of the diameter of the lens to the square of the diameter of the pupil.

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## CHAPTER VIII.

### ON CAUSTIC CURVES FORMED BY REFLEXION AND REFRACTION.

*Caustics formed by Reflexion.*—It has been already shown that rays of light incident on different points of a concave mirror at different distances from its axis are reflected to different foci in that axis. The rays thus reflected must, it is evident, cross one another at particular points, and wherever the rays cross they will illuminate the white ground on which they are received

with twice as much light as falls on other parts of the ground. These luminous intersections form curve lines, called *caustic lines* or *caustic curves*, and their nature and form will vary with the surface and inclination of the mirror, and the distance of the radiant point.

Caustic curves have received a good deal of attention since they were first discovered by Tschirnhausen in the latter part of the seventeenth century down to the present time. They have formed the subject of mathematical investigation by M. de la Hire, James and John Bernoulli, M. Bouguer, Dr. Priestley, Sir David Brewster, and other distinguished philosophers.

Their mode of formation and general properties may be thus explained. Let  $A B D$  be a concave spherical mirror (Fig. 31) whose centre is  $c$ , and whose focus for

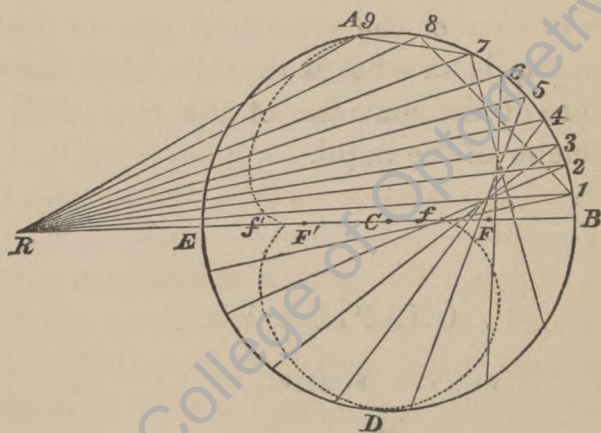


Fig. 31.

parallel and central rays is  $F$ . Let  $R A B$  be a diverging beam of light falling on the upper half,  $A B$ , of the mirror at the points 1, 2, 3, 4, 5, &c. If we draw lines to all these points from the centre  $c$ , and make the angles of reflexion equal the angles of incidence, we shall obtain the directions and foci of all the incident rays. The

ray  $R1$ , near the axis  $RB$ , will have its conjugate focus at  $f$ , between  $F$  and the centre  $C$ . The next ray,  $R2$ , will cut the axis near  $F$ , and so on with all the rest, the foci extending from  $C$  to  $F$ . By drawing all the reflected rays to these foci they will be found to intersect one another as in the figure, and form by their intersections the caustic curve  $Af$ . If light had been incident on the lower half of the mirror a similar caustic, shown by a dotted line, would also have been formed between  $D$  and  $f$ . If we suppose the point of incidence to move from  $A$  to  $B$ , the conjugate focus of any two contiguous rays, or an infinitely slender pencil of light diverging from  $R$ , will move along the caustic from  $A$  to  $f$ .

If we now suppose the convex surface  $ABD$  of the mirror to be polished, and the radiant point  $R$  to be placed as far to the right hand of  $B$  as it is now to the left, it will be found, by drawing the incident and reflected rays, that they will diverge after reflexion, and that when continued backwards they will intersect one another, and form the imaginary caustic  $Af'D$ , situated behind the convex surface, and exactly similar to the real caustic.

If we suppose the convex mirror  $ABD$  to be completed round the same centre,  $C$ , as at  $AED$ , and the pencil of rays still to radiate from  $R$ , they will form the imaginary caustic  $Af'D$ , smaller than  $AfD$ , and uniting with it at the points  $A$  and  $D$ .

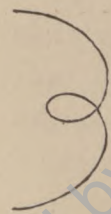
Let the radiant point  $R$  be now supposed to recede from the mirror, the line  $Bf$ , which is called the tangent of the real caustic  $AfD$ , will diminish, because the conjugate focus  $f$  will approach to  $F$ , and for the same reason the tangent  $EF'$  of the imaginary caustic will increase. When  $R$  becomes infinitely distant, or the incident rays parallel, the points  $ff'$ , called the cusps

of the caustic, will both coincide with  $F$  and  $F'$ , the principal foci, and will have the same size and form.

But if the radiant point  $R$  approaches to the mirror, the cusp  $f$  of the real caustic will approach to the centre  $c$ , and the tangent  $cf$  will increase; the cusp  $f'$  of the imaginary caustic will approach to  $E$ , and its tangent  $Ef'$  will diminish; and when the radiant point arrives at the circumference at  $E$ , the cusp  $f'$  will also arrive at  $E$ , and the imaginary caustic will disappear. At the same time, the cusp  $f$  of the real caustic will be a little to the right of  $c$ , and its two opposite summits will meet in the radiant point at  $E$ .

If we suppose the radiant point  $R$  now to enter within the circle  $ABDE$ , so that the distance from  $R$  to  $c$  is less than  $R$  to  $E$ , a remarkable double caustic will be formed: this will consist of two short ones of the common kind having their common cusp at  $f$  (Fig. 31), and of two long branches, which meet in a focus to the right of  $B$ .

With a white china bowl I have produced some curious caustics. If the bowl be held in the hand, and its concave surface turned towards a candle a few feet distant, the caustics will be formed at the bottom of the bowl. By inclining the upper edge of the bowl a little from the candle, the cusps will cross each other and form a figure similar to that of Fig. 32. If the upper edge of the bowl be now inclined gradually towards the candle, the former caustic gradually disappears, and the caustic is formed on the opposite side of the bowl; if the upper edge is still more



inclined towards the candle, a figure the reverse of 32 is produced, like Fig. 33. Let the bowl

be now moved by the hand, so that the most *distant point* in the edge of the bowl from the candle will gradually move round, and the above caustics will be seen to move around the bottom of the bowl.

I have also produced with a white wash-hand basin, 14 inches in diameter at the edge, and  $4\frac{1}{2}$  inches in greatest depth, not only very remarkable caustic curves, but some curious forms, some like ladies' fans, others like the wings of birds, and still more like the tails of fishes, such as the herring and mackerel. I will now describe the way I produced these forms. A lighted candle was placed on the chimney-piece; about 2 feet from the candle, measured horizontally, the basin was placed with its lower edge resting on the washstand, which was about 2 feet lower than the flame of the candle. The washstand was in a recess, and was partly in shadow. I turned the concave surface of the basin towards the candle, about  $\frac{5}{7}$  of the diameter of the basin being at the time in the shadow, and the remaining  $\frac{2}{7}$  in the light. Some of the forms that appeared on the bottom of the basin were like the figures 34 and 35.

Fig. 33.

The means by which I formed these figures and several others are within the reach of every one in his own home.

When I produced these figures, the upper part of the edge, or circumference of the basin, was inclined at an angle of about  $45^\circ$  from the perpendicular, and receding from the candle.

*Caustics formed by Refraction.*—If a glass globe filled with water, a solid spherical lens, or a round decanter filled with water, be placed in the light of the sun, lamp, or candle, and a sheet of white paper be laid flat

immediately behind the globe, lens, or decanter, we shall perceive on the paper a luminous figure bounded by two bright caustics, forming a sharp cusp or angle



Fig. 34.

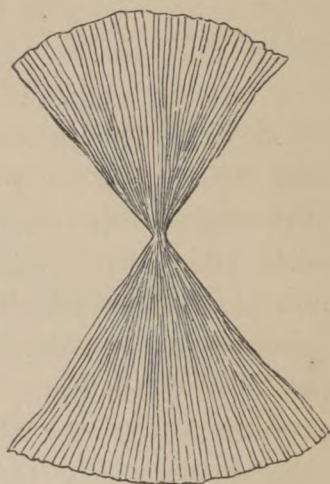


Fig. 35.

at the vertex of the refracted rays. The production of these curves depends upon the intersection of rays incident on the sphere, lens, or decanter at different distances from the axis, and which are refracted to foci at different points of the axis, and therefore cross one another. If a plano-convex eyeglass or lens be held

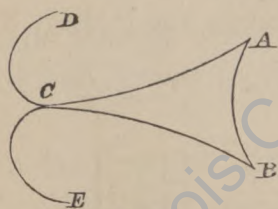


Fig. 36.

in this luminous figure so as to intercept the rays, a double caustic will be formed at or near the vertex of the figure, and will present an appearance similar to Fig. 36. In this figure, A B C is the part formed by the sphere or decanter, and D C E is the double caustic formed by the plano-convex eyeglass or lens.

## CHAPTER IX.

## PHYSICAL OPTICS—ANALYSIS OF LIGHT—ITS DECOMPOSITION INTO COLOURS.

*Solar Light Compound.*—White light as emitted from the sun, or from any luminous body, is, according to the investigations of Sir Isaac Newton, composed of seven different kinds of light, viz., red, orange, yellow, green, blue, indigo, and violet. These colours are rendered visible to the naked eye by refracting a beam of the sun's light through a prism of glass, and receiving the refracted rays on a white screen placed a few feet behind the prism.

If a hole about half an inch in diameter is made in the window shutter,  $E F$ , of a darkened room, there will be, if the sun is shining, a bright circular spot,  $P$ , formed upon the floor, or on a screen placed to receive it. This circular spot of light is an image of the sun, as may be proved by looking through a piece of smoked glass along the path of the beam, when the sun will be distinctly seen through the hole. If in the path of the beam,  $S L$ , we interpose a prism of glass  $A B C$  (Fig. 37),

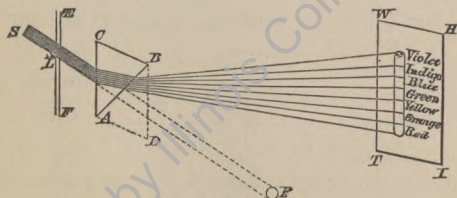


Fig. 37.

whose refracting angle is  $B A C$ , so that the beam of light may fall on its first surface  $C A$ , and emerge at the

same angle from its second surface B A, and if we receive the refracted beam on a white screen W H I T, we should expect, from the principles already explained, that the white beam which fell upon P would suffer only a change in its direction, and fall somewhere upon the screen W H I T, forming there a round spot like to that at P. This, however, is not the case. Instead of a white spot, there will be formed on the screen an elongated image of the sun, containing seven colours visible to the naked eye, viz., red, orange, yellow, green, blue, indigo, and violet. This elongated image of the sun is called the *solar spectrum*, the *prismatic spectrum*, or it is sometimes called the *Newtonian spectrum*, since the first satisfactory examination of the sun-light by prismatic decomposition was performed by Sir Isaac Newton. The lowest portion of the spectrum is a brilliant red; this red tones off gradually into orange, the orange into yellow, the yellow into green, the green into blue, the blue into indigo, and the indigo into violet.

It is extremely difficult for the sharpest eye to mark the boundary of the different colours; indeed, it is scarcely possible that any two persons should give the same limits to any particular colour. Allowing the total length of the spectrum to be 360, the following are the lengths of the several colours as determined by Newton and Fraunhofer:—

	Newton.	Fraunhofer.
Red . . . . .	45 . . . . .	56
Orange . . . . .	27 . . . . .	27
Yellow . . . . .	40 . . . . .	27
Green . . . . .	60 . . . . .	46
Blue . . . . .	60 . . . . .	48
Indigo . . . . .	48 . . . . .	47
Violet . . . . .	80 . . . . .	109
	<hr/>	<hr/>
Total length . . . . .	360 . . . . .	360

The differences in the lengths of some of the colours

are very striking ; indeed, the length occupied by each colour will depend upon the sort of glass, or other material, of which the prism is composed.

In order to examine each colour separately, Sir Isaac Newton made a hole in the screen, *W H I T* (Fig. 37), opposite the centre of each coloured space, and allowed that particular colour to fall upon a second prism placed behind the hole. This light was not lengthened or elongated as before, and was not refracted into any other colours. Hence he concluded that the light of each different colour had the same index of refraction ; and he called such light *simple* or *homogeneous*, white light being regarded as *heterogeneous* or *compound*. Sir Isaac Newton also proved experimentally that all the seven colours, when again combined and made to fall upon the same spot, formed, or recomposed, white light. This he established by various experiments. If the screen upon which the spectrum is received is brought nearer the prism, the rays begin to mix ; yet, even when brought close to the prism, the colours are evident. If another prism *B A D*, as shown by the dotted lines (Fig. 37), made of the same kind of glass, is placed with its angles in an opposite direction to the first prism, the coloured rays are again combined, and a white spot as before falls upon the floor.

It has been just stated that Sir Isaac Newton concluded that the light of each different colour had the same index of refraction. This is true only for the mean ray of each colour, for the rays of each colour being themselves differently refractible, or, as the term is more generally used, differently refrangible, according as they fall on different parts of the coloured space, they will, strictly speaking, have different indices of refraction.

Sir John Herschel has shown that by looking at the spectrum with a cobalt-blue glass, we perceive a ray, called by him the "extreme red," of a crimson colour, below the ordinary red of the spectrum; and by throwing the spectrum upon paper stained yellow by turmeric, a ray of high refrangibility becomes visible beyond the violet, which ray is of a peculiar neutral colour, and has been called a *grey* or *lavender* ray. Thus the number of colours in the spectrum is increased to nine. Professor Stokes has still further increased this number by the discovery of another colour beyond the lavender ray, which he has called the *fluorescent* ray, as it resembles the colour of some varieties of fluorspar; so that the number of colours in the prismatic spectrum is, according to the researches of these philosophers, further increased to ten.

*Decomposition of Light by Absorption.*—Sir David Brewster examined the nature of light by absorption; that is, by viewing the spectrum after the rays had been transmitted through differently-coloured substances or media, and he concludes that the solar spectrum consists of only *three primary colours*, viz., red, yellow, and blue.

As this distinguished philosopher has contributed more to the science of optics by his discoveries and inventions than any other philosopher of recent times, I shall describe the manner by which he reduced the number of colours in the spectrum to three in nearly his own words. If we measure the quantity of light which is reflected from the surfaces and transmitted through the substance of transparent bodies, Sir David says, we shall find that the sum of these quantities is always less than the quantity of light which falls upon the body. Hence we may conclude that a certain portion of light is *lost* in passing through the most trans-

parent bodies. This loss arises from two causes. A part of the light is scattered in all directions by irregular reflexion from the imperfectly-polished surface of particular media, or from the imperfect union of its parts; while another, and generally a greater portion, is *absorbed*, or stopped by the particles of the body. Coloured fluids, such as black and red inks, though equally homogeneous, stop or absorb different kinds of rays, and when exposed to the sun they become heated in different degrees; while pure water seems to transmit all the rays equally, and scarcely receives any heat from the passing light of the sun. When we examine more minutely the action of coloured glasses and coloured fluids in absorbing light, many remarkable phenomena present themselves, which strikingly elucidate this curious subject. If we take a piece of blue glass, like that generally used for finger glasses, and transmit through it a beam of white light, the light will be a fine deep blue. This blue is not a simple homogeneous colour, like the blue or indigo of the spectrum, but is a mixture of all the colours of white light which the glass has not absorbed; and the colours which the glass has absorbed are those which the blue wants of white light, or which, when mixed with this blue, would form white light. In order to determine what these colours are, let us transmit through the blue glass the prismatic spectrum (Fig. 37), or, what is the same thing, let the observer place his eye behind the prism  $BAC$ , and look through it at the sun, or rather at a circular aperture made in the window shutter of a dark room; he will then see through the prism the spectrum as far below the aperture as it was above the spot  $p$  when shown on the screen. Let the blue glass be now interposed between the eye and the prism, and a remarkable

spectrum will be seen, deficient in a certain number of its differently coloured rays. A particular thickness absorbs the middle of the red space, the whole of the orange, a great part of the green, a considerable part of the blue, a little of the indigo, and very little of the violet. The yellow space, which has not been much absorbed, *has increased in breadth*. It occupies part of the space formerly covered by the orange on one side, and part of the space formerly covered by the green on the other. Hence it follows that the blue glass has absorbed the red light, which when mixed with the yellow light constitutes orange, and has absorbed also the blue light, which when mixed with the yellow constitutes the part of the green space next to the yellow. We have, therefore, by absorption, decomposed *green* light into *yellow* and *blue*, and *orange* light into *yellow* and *red*; it consequently follows that the orange and green rays of the spectrum, though they cannot be decomposed by prismatic refraction, can be decomposed by absorption, and actually consist of two different colours possessing the same degree of refrangibility. *Difference of colour is therefore not a test of difference of refrangibility*, and the conclusion deduced by Newton is no longer admissible as a general truth, "That to the same degree of refrangibility ever belongs the same colour, and to the same colour ever belongs the same degree of refrangibility."

With the view of obtaining a complete analysis of the spectrum, I have examined the spectra produced by various bodies, and the changes which they undergo by absorption, when viewed through various coloured media, and I find that the colour of every part of the spectrum may be changed, not only in intensity, but in colour, by the action of particular media; and from

these observations I conclude that the solar spectrum consists of three spectra of equal lengths, viz., a *red* spectrum, a *yellow* spectrum, and a *blue* spectrum. The *primary red* spectrum has its maximum of intensity about the middle of the red space in the solar spectrum, the *primary yellow* spectrum has its maximum in the middle of the yellow space, and the *primary blue* spectrum has its maximum between the blue and the indigo space. The two minima of each of the three primary spectra coincide at the two extremities of the solar spectrum.

From this view of the constitution of the solar spectrum we may draw the following conclusions:—

1. *Red, yellow, and blue* light exist at every point of the solar spectrum.

2. As a certain portion of *red, yellow, and blue* constitutes *white* light, the colour of every point of the spectrum may be considered as consisting of the predominating colour at any point mixed with white light. In the red space there is more red than is necessary to make white light with the small portions of yellow and blue which exist there; in the yellow space there is more yellow than is necessary to make white light with the red and blue; and in the part of the blue space which appears violet there is more red than yellow, and hence the excess of red forms a violet with the blue.

3. By absorbing the excess of any colour at any point of the spectrum, above what is necessary to form white light, we may actually cause white light to appear at that point, and this white light will possess the remarkable property of remaining white after any number of refractions, and of being decomposable only by absorption. Such a white light I have succeeded in developing in different parts of the spectrum. These

views harmonize in a remarkable manner with the hypothesis of three colours, which has been adopted by many philosophers, and which others had rejected from its incompatibility with the phenomena of the spectrum.

In opposition to the foregoing views of Sir David Brewster, Robert Hunt, Esq., F.R.S., states, in his "Researches on Light," that M. Bernard, of Bordeaux, has shown :—1st. That the intensity of the light has such influence on the sensation of colour, that it may not only modify the aspect of the entire spectrum, but certain tints may disappear altogether. 2nd. That the absorption produced by the action of media hitherto employed on the tints of the spectrum only affects the intensity of the light, and does not influence the nature of the colours. And, 3rd. That far from destroying the bond which appears to exist between refrangibility and coloration, observations made with care tend to confirm the opposite opinion ; everything, indeed, leads to the belief that to each ray of a given refrangibility, and possessing a determined intensity, corresponds a colour susceptible of being reproduced identically under like circumstances.

M. Helmholtz has recently subjected the spectrum to a searching analysis, Mr. Hunt further states, and the result is opposed to the views of Brewster, while they confirm those of Newton. M. Helmholtz is disposed to refer the phenomena observed by Brewster, when viewing the spectrum through differently-coloured media, to a diffusion of the light of the adjoining rays over the particular ray under examination ; and he supposes this to arise from extra refraction in the prism and in the transparent-coloured laminae employed, by dust, striæ, and the like, producing secondary images. Helmholtz

has adopted the following arrangement, to make the experiment in such a manner as to avoid all influence of diffusion. A solar spectrum is produced in the usual way, by means of a prism, and a lens placed at a suitable distance from a narrow slit admitting the solar rays. The screen which receives the spectrum is itself perforated by a slit, which can be adjusted at will to any colour; in this way is insulated a very slender luminous pencil of any of the rays under examination, which are rendered thus perfectly homogeneous. This pencil is received on a second prism, to which succeeds a lens; the group of homogeneous rays throws upon a suitably-adjusted screen a narrow image of the slit. It will be evident that by such an arrangement as this a pencil of light may be obtained which will be pure, the very trifling quantity of diffused light by which it may be accompanied being too feeble to be taken into account. The results obtained by this method support the Newtonian law of the strict relation of colour to the refracting angle. For example, pure yellow, seen through blue glass of any thickness whatsoever, always preserves its yellow tint, never passing into white.

"Such is the state of the discussion," Mr. Hunt observes, "as to the constitution of the spectrum. Whether the theory of the seven prismatic rays of Newton it to be adopted, or the three spectra of Brewster, it is evident it must undergo much modification."

I have performed many experiments with prisms during the last ten years, and am fully persuaded that Sir Isaac Newton, whose memory every true lover of science sincerely respects, was led unconsciously into mistakes by the *mode* of making his experiments.

The experiments I have made not only reconcile the views of Sir Isaac Newton, Sir David Brewster, and

other modern philosophers, respecting the colours of the solar spectrum, but they go farther, and establish the doctrine of colours held by some of the ancient Greeks and Romans, namely, that *colours are produced by intermixtures of light and shade*.

If, when in a room, we look through a prism, with its refracting angle downwards, at a window-sash, we shall find that two colours will appear under each horizontal sash-bar, and one colour at the upper side of the bar. The two colours under the bar are, *red next the bar*, and *yellow* below the red; the colour at the upper side of the bar is *blue*. If the refracting angle of the prism be reversed, the position of the colours will be reversed also; that is, if the red and yellow be above the bar, the blue will be at the lower side of the bar. The same order of the colours will be observed in looking through a prism at a black line extending in a right and left direction on a sheet of white paper placed in a vertical, horizontal, or inclined position. In short, at whatever object we look through the prism, provided the object presents any contrast of *light* and *shade*, the red, yellow, and blue colours will be seen, or these colours will be seen more or less intermixed or combined, according to the positions of the parts of the object presenting the light and shade.

Now let us apply these simple facts to Sir Isaac's spectrum. The colours produced by the prism below the upper side of the hole or slit through which he admitted the light were *red* and *yellow*; the colour produced above the lower side of the hole or slit was *blue*; these three colours being allowed to proceed at differently refracted angles to a screen placed several feet from the prism, became more or less intermixed, and formed on the screen the seven colours of Sir Isaac's

spectrum. Indeed, on account of the small size of the hole—one-fourth inch in diameter—through which Sir Isaac admitted the light, the red, yellow, and blue colours must have intermixed before these colours left the second surface of the prism.

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## CHAPTER X.

### ON THE DISPERSION OF LIGHT.

IN the prismatic spectrum formed by the prism  $ABC$  (Fig. 37), the *green*, which occupies the middle space, has been called the *mean ray of the spectrum*; the index of refraction which belongs to it is called the *mean refractive power* of the prism; and the angle which the middle green ray forms with the line  $sr$ , the mean refraction of the prism.

Sir Isaac Newton in his experiments made use of prisms of different substances, yet he never observed that they formed spectra whose lengths were different when the mean refraction of the green ray was the same. If a prism be made of glass plates, and filled with oil of cassia, and its refracting angle be so adjusted that the middle of the spectrum which it forms falls exactly on the middle green ray in the spectrum formed with the glass prism, then it will be found that the spectrum of the oil of cassia prism will be more than twice the length of that of the glass prism; the oil of cassia is therefore said to disperse the rays of light more than the glass, that is, to separate the extreme red and violet rays more from the mean green ray, and to have a greater *dispersive power*.

In order to find a distinct measure of the dispersive power of a body, let us suppose that the prism  $ABC$  is

filled with water, and that by the methods described in Chap. II. we find the index of refraction for the extreme violet ray to be 1.330, and that of the extreme red ray to be 1.342; then the difference of these, or 0.012, would be a measure of the dispersive power of water, if it and all other bodies had the same mean refraction; but this not being the case, the dispersive power must be measured by the relation between the separation of the extreme rays and the mean refraction, or between the indices of refraction for the extreme red and the extreme violet, and the difference between the sines of incidence and refraction, to which the mean refraction is always proportional.

The difference between the indices of the red and violet rays in the diamond is 0.056, nearly five times greater than 0.012, which it is in water; but the difference between the sines of incidence and refraction in the diamond is 1.439, nearly five times greater than 0.336, which it is in water; so that the real dispersive power of diamond is not much greater than that of water. The ratio of the dispersive powers is thus expressed :—

$$\text{For water} \quad \frac{1.342 - 1.330}{1.336 - 1} \text{ or } \frac{0.012}{0.336} = 0.0357 \text{ dispersive power.}$$

$$\text{For diamond} \quad \frac{2.467 - 2.411}{2.439 - 1} = \frac{0.056}{1.439} = 0.0388 \text{ dispersive power.}$$

In the following table the dispersive powers of various media are given as determined by Sir David Brewster. The first column contains the dispersive powers; and the second, the difference of the indices of refraction for the red and violet rays, or the part of the whole refraction to which the dispersion is equal. Therefore if we add the half of the numbers in the last column to the index of refraction as given in page 13, we shall



	Dispersive power.	Diff. of index of refr. for extreme rays.
Oil of pimento . . . . .	0.052	0.020
Flint glass . . . . .	0.052	0.026
Oil of angelica . . . . .	0.051	0.025
Oil of thyme . . . . .	0.050	0.024
Oil of fenugreek . . . . .	0.050	0.024
Oil of caraway seed . . . . .	0.049	0.024
Gum thus . . . . .	0.048	0.028
Oil of juniper . . . . .	0.047	0.022
Nitric acid . . . . .	0.045	0.019
Canada balsam . . . . .	0.045	0.021
Cajeput oil . . . . .	0.044	0.021
Oil of rhodium . . . . .	0.044	0.022
Oil of poppy . . . . .	0.044	0.220
Zircon (gr. refr.) . . . . .	0.044	0.045
Muriatic acid . . . . .	0.043	0.016
Gum copal . . . . .	0.043	0.024
Nut oil . . . . .	0.043	0.022
Oil of turpentine . . . . .	0.042	0.020
Felspar . . . . .	0.042	0.022
Balsam of capivi . . . . .	0.041	0.021
Amber . . . . .	0.041	0.023
Calcareous spar (gr.) . . . . .	0.040	0.027
Oil of rapeseed . . . . .	0.040	0.019
Sulphate of iron . . . . .	0.039	0.019
Diamond . . . . .	0.038	0.056
Oil of olives . . . . .	0.038	0.018
Gum mastic . . . . .	0.038	0.022
Oil of rue . . . . .	0.037	0.016
Beryl . . . . .	0.037	0.022
Ether . . . . .	0.037	0.012
Selenite . . . . .	0.037	0.020
Alum . . . . .	0.036	0.017
Castor oil . . . . .	0.036	0.018
Crown glass, green . . . . .	0.036	0.020
Gum arabic . . . . .	0.036	0.018
Water . . . . .	0.035	0.012
Citric acid . . . . .	0.035	0.019
Glass of borax . . . . .	0.034	0.018
Garnet . . . . .	0.034	0.018
Chrysolite . . . . .	0.033	0.022
Fluor spar . . . . .	0.022	0.010
Crown glass . . . . .	0.033	0.018
Oil of wine . . . . .	0.032	0.012
Glass of phosphorus . . . . .	0.031	0.017
Plate glass . . . . .	0.032	0.017
Sulphuric acid . . . . .	0.031	0.014
Tartaric acid . . . . .	0.030	0.016
Nitre (least ref.) . . . . .	0.030	0.009
Borax . . . . .	0.030	0.014
Alcohol . . . . .	0.029	0.011
Sulphate of barytes . . . . .	0.029	0.011

	Dispersive power.	Diff. of index of refr. for extreme rays.
Rock crystal . . . . .	0.026	0.014
Tourmaline. . . . .	0.028	0.019
Emerald . . . . .	0.026	0.015
Borax glass (1 bor. 2 silex) . . . . .	0.026	0.014
Blue sapphire . . . . .	0.026	0.021
Bluish topaz . . . . .	0.025	0.016
Chrysoberyl . . . . .	0.025	0.019
Blue topaz . . . . .	0.024	0.016
Sulphate of strontites . . . . .	0.024	0.015
Prussic acid . . . . .	0.027	0.008
Cryolite . . . . .	0.022	0.007

It appears by the preceding table that different bodies possess very different powers of dispersing or of separating the coloured rays of light.

If we form two spectra of equal lengths by two bodies of very different dispersive powers, such as oil of cassia and sulphuric acid enclosed in hollow glass prisms, we shall find a remarkable difference between them. Let A B (Fig. 38)

be a spectrum produced by a prism of oil of cassia, and C D a spectrum produced by a prism of sulphuric acid; by carefully examining these two prisms we shall find that the least refrangible colours, red, orange, and yellow, will occupy less spaces, or will be more contracted in the oil of cassia spectrum than in the sulphuric acid one; while the most refrangible colours, blue, indigo, and violet, will occupy larger spaces, or will be more expanded.

Therefore the coloured spaces have not the same ratio to each other as the lengths of the spectrum; hence this property is called the *irrationality*

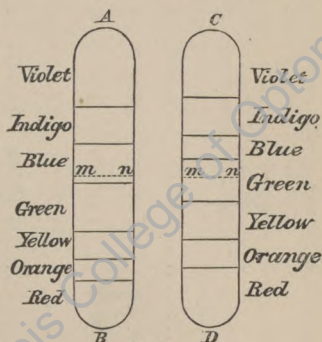


Fig. 38.

TABLE OF THE INDICES OF REFRACTION OF THE MEAN RAYS OF EACH OF THE  
PRISMATIC COLOURS FOR CERTAIN MEDIA.

Refracting Substances.	Mean Red Ray.	Mean Orange Ray.	Mean Yellow Ray.	Mean Green Ray.	Mean Blue Ray.	Mean Indigo Ray.	Mean Violet Ray.
Flint glass, No. 13 .....	1·627749	1·629681	1·635036	1·642024	1·648260	1·660285	1·671062
Crown glass, No. 9 .....	1·525832	1·526849	1·529587	1·533005	1·536052	1·541657	1·546566
Water .....	1·330935	1·331712	1·333577	1·335851	1·337818	1·341293	1·344177
Water .....	1·330977	1·331709	1·333577	1·335849	1·337788	1·341261	1·344162
Solution of potash .....	1·399629	1·400515	1·402805	1·405632	1·408082	1·412579	1·416368
Oil of turpentine .....	1·470496	1·471530	1·474434	1·478353	1·481736	1·488198	1·493874
Flint glass, No. 3 .....	1·602042	1·603800	1·608494	1·614532	1·620042	1·630772	1·640373
Flint glass, No. 30 .....	1·623570	1·625477	1·630585	1·637356	1·643466	1·655406	1·666072
Crown glass, No. 13 .....	1·524312	1·525299	1·527982	1·531372	1·534337	1·539908	1·544684
Crown glass, letter M.....	1·554774	1·555933	1·559075	1·563150	1·566741	1·573535	1·579470
Flint glass, No. 23, prism 60° ....	1·626596	1·628469	1·633667	1·640495	1·646756	1·658848	1·669686
Flint glass, No. 23, prism 45° ....	1·626564	1·628451	1·633666	1·640544	1·646780	1·658849	1·669680

of dispersion, or of the coloured spaces in the spectrum. This property is clearly shown in Fig. 38, by which it also appears that the mean ray,  $m n$ , is among the blue rays in the oil of cassia spectrum, and among the green rays in the sulphuric acid spectrum.

Thus it appears that although the indices of refraction of the extreme rays for any two substances may be equal, the indices of refraction of each of the intermediate rays may be unequal, and the differently-coloured spaces in the two spectra may be also unequal.

In the table opposite the indices of refraction corresponding to the mean rays of each of the seven principal dark lines in the spectrum are given for several media or substances, according to the experiments of Fraunhofer.

By taking the difference between any two indices the dispersion proper to any two of the prismatic colours will be found, and by taking the difference between the extreme indices the total dispersion produced by each medium will be found. For example, the index of the red ray produced by flint glass No. 13 is 1.627749, and the index of the blue ray produced by the same medium is 1.648260; the difference, 0.020511, is the dispersion of the mean red and blue rays; the index of the red ray for the same medium being 1.627749, and the index for the violet ray being 1.671952, the difference is 0.043313, which is the total dispersion of the red and violet rays produced by flint glass No. 13.

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## CHAPTER XI.

### ON THE PRINCIPLE OF ACHROMATIC TELESCOPES.

THE application of the principle of the *dispersion of light*, explained in Chapter X., to the improvement of

the refracting telescope, forms one of the most interesting portions of optical science. Sir Isaac Newton concluded that it was impossible by the combination of lenses to produce refraction without colour, because he believed that all media, or substances, whether solid or fluid, had the same dispersive power, or produced the same length of spectrum in proportion to their mean refraction; yet soon after the death of that eminent philosopher, it was accomplished by Mr. Dollond, who constructed excellent refracting telescopes *without colour*, or, as they are called, *achromatic* telescopes.

If a convex lens is made of *crown glass*, whose index of refraction is 1.519, and dispersive power 0.036, and a concave lens of *flint glass*, whose index of refraction is 1.589, and dispersive power 0.0393, and if the focal length of the convex crown-glass lens is made  $4\frac{1}{3}$  inches, and that of the concave flint-glass lens  $7\frac{2}{3}$  inches, they will form, when placed close together, a lens with a focal length of 10 inches, and will refract parallel rays of white light striking on the convex lens to a single focus nearly free of colour. The great point to be attained is to find two substances of different refractive and dispersive powers, and capable of producing spectra of equal length, and in which the coloured spaces are all equal. If such substances were found a perfect achromatic lens would be produced; but as no such substances have as yet been found, other means have been adopted to remove the imperfection.

Dr. Blair discovered that muriatic acid produced a spectrum in which the green rays were among the most refrangible. But as muriatic acid has too low a refractive and dispersive power to fit it for being used as a concave lens along with a convex lens of crown glass, he conceived the idea of increasing the refractive

and dispersive power of the muriatic acid by mixing it with metallic solutions, such as muriate of antimony; and he found he could do this to the requisite extent without altering its law of dispersion, or the proportion of the coloured spaces in its spectrum. By enclosing muriate of antimony,  $L L$ , between two convex lenses of crown glass, as  $A B, C D$  (Fig. 39), he succeeded in refracting parallel rays,  $R A, R B$ , to a single focus  $F$ , without the least trace

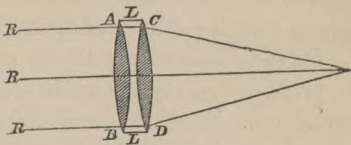


Fig. 39.

of colour. Through telescopes made with lenses of this description Professors Robinson and Playfair saw double stars with a distinctness and degree of perfection which astonished them.

In practice the materials which have been found most suitable for achromatic lenses are flint glass and crown glass, which differ considerably in both their refracting and dispersing powers. The refracting and dispersing powers of these sorts of glass vary according to the proportions of their constituents, but they may be always rendered such as to fulfil the conditions necessary for an achromatic lens.

The forms of the lenses shown in Fig. 40 are those of a double concave of flint glass, and a double convex of crown glass. It is, however, neither necessary nor expedient that these forms should be always adopted. The crown-glass lens may be double convex, with unequal convexities, or it may be plano-convex, or even meniscus. The flint-glass lens may be in like manner double-concave, with unequal concavities, or it may be plano-concave, or concavo-convex. In the same way



Fig. 40.

the radii of the curves of the surfaces may be indefinitely varied, the compound lens having still the same focal length.

The practical optician, it will thus be seen, has a wide range in the construction of achromatic lenses, of which the most eminent have availed themselves with great skill and address, so as to remove, by the happy combination of curves, not only the spherical aberration, but also the chromatic aberration of the eyeglass, and the spherical distortion

*On the Illuminating Power of the Spectrum.*—By the experiments of Fraunhofer it appears that the place of maximum illumination in the solar spectrum is at the boundary of the orange and yellow rays. Calling the illuminating power at this place 100, the light at other places will be as follows:—At the extremity of the red, 0·0; near the extremity of the red, 3·2; near the middle of the red, 9·4; in the orange, 64·0; boundary of the orange and yellow, 100·0; in the green, 48·0; in the blue, 17·0; in the indigo, 3·1; near the middle of the violet, 0·56; extremity of the violet, 0·0.

*Dark Lines across the Spectrum.*—In the year 1802 two dark lines were observed by Dr. Wollaston to extend across the spectrum formed by a fine prism of flint glass, free of veins, when the luminous rays were admitted through a slit the twentieth of an inch wide. This discovery did not attract much of his attention at the time. Without knowing of Dr. Wollaston's discovery, M. Fraunhofer discovered that throughout the whole length of the spectrum it is nearly all covered with these dark lines running parallel to one another, and perpendicular to the length of the spectrum. He also ascertained that these lines are altogether independent both of the magnitude of the refracting angle, and of the matter of the prism. The number of these

dark lines observed by Fraunhöfer amounts to 590. This number has been increased by Sir David Brewster, who observed no less than 2,000 dark lines in a spectrum which he examined.

In order to observe these dark lines it is necessary to use prisms free from veins, to exclude all diffused or extraneous light, and to stop those rays that form the coloured spaces which we are not examining. It is necessary also to use a telescope which magnifies eight or ten times.

*Heating or Calorific Power of the Spectrum.*—It had been supposed up to about the commencement of the nineteenth century that the heating power in the spectrum would be proportional to the quantity of light. The late Sir William Herschel, however, proved by experiment that the heating power gradually increased from the violet to the red extremity of the spectrum. He also found that the thermometer continued to rise when placed beyond the red end of the spectrum, where not a single ray of light was then perceived. Sir John Herschel has since discovered the "extreme red" ray in this place by looking through cobalt-blue glass (see page 70). Sir Wm. Herschel determined that the rays invisible to the naked eye exerted a considerable heating power  $1\frac{1}{2}$  inch distant from the extreme red ray visible to the naked eye, even though the thermometer was placed at a distance of 52 inches from the prism.

These experiments were repeated by Sir Henry Englefield, with additional precautions against error, and he found that the thermometer rose in the following order :—

In the blue rays in . . .	3	minutes from $55^{\circ}$ to $56^{\circ}$	or $1^{\circ}$
In the green rays in . . .	3	" 54 "	58 " 4
In the yellow rays in . . .	3	" 56 "	62 " 6
In the red rays in . . .	$2\frac{1}{2}$	" 56 "	72 " 16
In the confines of the red in	$2\frac{1}{2}$	" 58 "	$73\frac{1}{2}$ " $15\frac{1}{2}$
Below the visible red in .	$2\frac{1}{2}$	" 61 "	79 " 18

M. Berard obtained similar results, excepting that he found the greatest heat at the very extremity of the visible red, instead of beyond. Still more recently M. Seebeck has confirmed the foregoing results, excepting that he found the place of the greatest heat varies with the substance of which the prism is made. Seebeck was assisted in his experiments by M. Wunsch; they came to the following conclusions:—

Substance of the Prism.	Colour of space in which the heat is greatest.
Water . . . . .	yellow
Alcohol . . . . .	"
Oil of turpentine . . . . .	"
Sulphuric acid . . . . .	orange
Solution of muriate of ammonia . . . . .	"
Solution of corrosive sublimate . . . . .	"
Crown glass . . . . .	middle of the red
Plate glass . . . . .	"
Flint glass . . . . .	beyond the " visible red

Sir John Herschel has more recently made a series of experiments on the heating power of the spectrum, by trying the varying effects of its power when thrown upon sheets of the thinnest post paper smoked on one side in the flame of oil of turpentine, the smoke of a candle, or blackened with Indian ink, till it is coated with a film of deposited black, as nearly uniform as possible, and soaked on the other side with rectified spirits of wine, which makes the paper uniformly black. The spectrum being thrown upon the wetted side of the paper thus prepared, the heating power of its different parts is manifested by the varying degree of its bleaching power upon the paper produced by the evaporation of the spirits of wine.

The result obtained in this way was, that the heating power extended over the whole length of the spectrum, but at a point considerably beyond the limit of the extreme red (visible to the naked eye) the heating

power is a maximum or greatest, having gradually increased in ascending from the lowest limit to this point. The heating power then diminishes slightly for a short space, and again increasing, attains a second maximum. It then diminishes until it ceases altogether, after which it again increases until it attains another maximum, after which it again diminishes, vanishes, and reappears, and increases until it attains a fourth maximum, and still again a fifth maximum is faintly indicated.

M. Melloni has shown by his experiments that bodies are not alike transparent to light and heat. Black mica, obsidian, and black glass in thin laminæ, although nearly opaque to light, yet allow a large quantity of radiant heat to pass through them, and are called by Melloni *diathermic* bodies; while glasses of a green colour, in combination with a layer of water, or a very clear plate of alum, are called *adiathermic*, from their being perfectly opaque for heat, notwithstanding light passes through them freely. These results tend to show that light and heat, though keeping company as it were in the sunbeam, are distinct solar emanations, and not merely different states of one power.

*On the Chemical Influence of the Spectrum.*—It has long been known that sunlight changes the colour of certain substances. The celebrated chemist Scheele first observed that muriate of silver is rendered much blacker by the *violet* than by any of the other visible rays of the spectrum. This fact enabled Daguerre to discover the art of producing portraits, called after the discoverer Daguerreotypes, by the action of light on plates of copper, covered with certain deposits of silver. The same fact also was the germ from which has grown the art of photography, which has elevated and enriched the arts of painting, sculpture, and architecture.

Since the art of photography has been developed to such importance, a great number of interesting experiments have been made upon the chemical effects of the spectrum. Some of the most distinguished philosophers of the present age have devoted much attention to the subject. The limits of this work preclude an examination of all the researches that have been made. It appears, however, from the valuable experiments of M. Edmund Becquerel, Sir John Herschel, Mr. Robert Hunt, and M. Niépce de Saint Victor, that the chemical, or *actinic*, influence of the spectrum upon various mineral and vegetable preparations generally extends from the green rays to the most refrangible violet rays.

By Mr. Hunt's researches, it appears that the chemical influence of the spectrum on twenty-nine different mineral and vegetable preparations extended, in all cases but one, from the green to the most refrangible violet; the sole exception being the juice of the ten weeks' stock, in which case the chemical influence extended only to the middle of the violet. A remarkable exception is also presented by this juice—the maximum chemical, or actinic, influence is exerted upon it at the middle of the yellow, where no influence is exerted upon any of the mineral preparations. In twenty-five of the twenty-nine preparations, the chemical influence extended beyond the most refrangible violet ray, and in eleven cases of the twenty-nine, the chemical, or actinic, influence extended even beyond the most refrangible fluorescent ray. In four of the vegetable preparations, viz., the juices of the *Corchorus Japonica*, ten weeks' stocks, wallflowers, and the green of leaves, the chemical, or actinic, influence of the spectrum extended over the yellow and orange, and

near to the least refrangible visible red ray. The maximum chemical effect on the preparations of *Corchorus Japonica* and wallflowers was at the middle of the indigo, and on that of the green of leaves at the boundary of the blue and indigo.

Assuming the length of the Newtonian, or visible, spectrum to be 40, by a scale of equal parts, the heat, or caloric, spectrum extended over 75 of such parts, according to some of Mr. Hunt's experiments, and the actinic, or chemical, spectrum over 86 of such parts, so that the chemical influence of the spectrum extended over a space more than twice the length of the visible luminous spectrum. The foregoing results coincide with some experiments of Sir John Herschel, who found that the chemical, or actinic, influence of the spectrum on paper prepared with nitrate of silver, and washed with hydrobromate of potash, extended over 116.77 equal parts, of which the visible luminous spectrum was only 53.92 parts.

*On producing Coloured Pictures Photographically.*—Various attempts have been made to obtain photographs of objects in their natural colours. These attempts have been so far successful as to produce photographs in which every colour of the original was faithfully represented; even the iridescent colours of the peacock's feather have been beautifully photographed. It is, however, not yet quite certain whether any means have been discovered by which the colours can be permanently fixed, as hitherto they have slowly faded away, and become one uniform reddish tint. It is generally admitted that, up to the present time, the most successful photographer in producing coloured pictures is M. Niépce de Saint Victor, whose process is this:—He takes a Daguerreotype, or silver-

coated plate, and dips it into a weak solution of hypochlorite of sodium, having a specific gravity of 1.35, until it has assumed a bright pinkish hue. The plate is then covered with a solution of dextrine, saturated with chloride of lead; it is then dried, and subsequently submitted to the action of heat for several hours until the temperature of the plate reaches from  $95^{\circ}$  to  $100^{\circ}$ , or else exposes the plate to the rays of the sun as a substitute for artificial heat, under a sheet of paper which had been steeped in an acid solution of sulphate of quinine. The plate is then ready to be placed in the camera obscura, and to receive the coloured picture of the spectrum, or any other object.

It is said that he has succeeded in increasing the stability of the colours developed on the sensitive surface by covering the plate with an alcoholic solution of gum benzoin. This branch of photography has been called *Heliochromie*.\*

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## CHAPTER XII.

### BREADTH OF WAVES OF LIGHT—INFLEXION OR DEFRAC- TION OF LIGHT—LAW OF INTERFERENCE.

THE following method of measuring the breadth of waves of differently-coloured light was used by Sir Isaac Newton.

He placed a flat plate of glass, *DE* (Fig. 41), upon a convex lens of glass, the surface of which is represented

\* It is not the object of this treatise to describe photographic processes generally. Those who wish to obtain full information respecting the most approved processes in practical photography will find it in M. Van Monkhoven's Treatise on "Photography," No. 79, Weale's Rudimentary Series.

by  $A B$ , but which must be supposed to have infinitely less curvature than that shown in the figure. The under surface of the flat plate will touch the vertex of the convex lens at  $c$ , and the further any point on the under surface is from  $c$ , the greater the distance

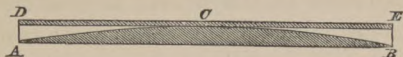


Fig. 41.

between the surfaces of the two glasses. If  $c$  be taken as a centre, and a circle be described round it, at all points of that circle the surfaces of the glasses will have the same distances between them, and the greater that circle is, the greater will be the distance between the surfaces of glass.

The glasses having been thus arranged, Newton found that, by letting a beam of red light fall on the surface of the glass  $D E$ , a black spot appeared at the centre  $c$ , where the glasses touched; that immediately around this spot there appeared a circle of red light; beyond that circle a dark ring; that outside of that dark ring there was another circle of red light, still having the point  $c$  as its centre. Outside this circle another dark ring appeared, beyond which there was another circle of red light, and so on, a series of circles of red light alternated with dark rings being formed, all having the point  $c$  as their common centre.

The distances between the surfaces of glass at which the successive circles of red light were found were too small to be directly measured, but they were easily calculated by measuring the diameters of the circles of light; and, knowing the diameter of the convex surface of the lens  $A C B$ , this was a simple problem in geometry easily solved with the greatest accuracy.

Newton found, on making these calculations, that the distance between the glass surfaces where the second red circle was formed was double the distance corresponding to the first; that at the third red circle the distance was triple that of the first, and so on. Of course it followed that wherever the dark rings were formed, the distances between the glass surfaces were not an exact number of times the space corresponding to the first red circle.

Newton perceived that these phenomena were the direct manifestation of those effects which corresponded to the breadth or amplitude of the waves of light in the undulatory theory, although he used the corpuscular nomenclature. The space between the surfaces of glass at the first red ring was the breadth of a single wave, the space at the second red circle the breadth of two waves, and so on. Within the first red circle the space between the glasses being less than the breadth of a wave, the propagation of the undulation was stopped, and darkness ensued; in like manner, in the space corresponding to the second dark ring, the distance between the glasses being greater than the breadth of one wave, but less than the breadth of two, the propagation was again stopped, and darkness produced. But at the second red circle, the space being equal to the breadth of two waves, the undulations were reflected, and the red ring produced, and so on.

It then became evident that, to measure the breadth of the red waves, it was only necessary to calculate the distance between the glasses at the first red ring.

*Number of Waves or Undulations in an Inch.*—When light of other colours was let fall upon the glass, a similar system of luminous rings was produced, but it was found in each case that the first ring varied in its

diameter according to the colour of the light, and therefore that the breadth of the waves of lights of different colours is different. It appeared that the waves of red light were the largest; orange came next to them; then yellow, green, blue, indigo, and violet succeeded each other, the waves of each being less than those of the preceding. But the most astonishing part of this investigation was the minuteness of these waves. It appeared that the waves of red light were so minute, that 40,000 of them would be comprised within an inch, while the waves of violet light were so small that 60,000 would be contained within an inch; the waves of light of other colours were of intermediate magnitudes.

*Table of Undulations.*—In the annexed table are given the length of the waves of each prismatic colour, the number of them which measure an inch, and the number of waves, pulsations, or undulations per second which strike the eye.

Colour.	Length of an undulation in parts of an inch.	Number of undulations in an inch.	Number of undulations per second.
Extreme red (visible)	0.0000266	37640	458,000000,000000
Red .....	0.0000256	39180	477,000000,000000
Orange .....	0.0000240	41610	506,000000,000000
Yellow .....	0.0000227	44000	535,000000,000000
Green .....	0.0000211	47460	577,000000,000000
Blue .....	0.0000196	51110	622,000000,000000
Indigo .....	0.0000185	54070	658,000000,000000
Violet .....	0.0000174	57490	699,000000,000000
Extreme violet ....	0.0000167	59750	727,000000,000000

In this table, which was calculated by the eminent Dr. Young, the numbers of waves or undulations per second are given in round numbers, so as to render the principles of the investigation as intelligible as possible.

The results contained in the table can scarcely fail to excite in us sentiments of the greatest wonder and astonishment. It is well known that solar light moves at the rate of about 200,000 miles per second; it necessarily follows that a ray of light 200,000 miles in length must enter the pupil of the eye each second, and as the perception of light and colour is produced by pulsations of the membrane of the eye vibrating in accordance with each ethereal undulation or wave propagated from a visible object, whenever we behold a red object, the retina, or membrane, of the eye trembles or pulsates upwards of 477,000,000,000,000 times every second. For each of the other colours of the spectrum the number of vibrations the eye makes in a second is still greater; when violet light is perceived it trembles at the rate of about 720,000,000,000 times in a second.

That man should be able to measure with certainty such almost infinitely small portions of time and space is most wonderful; for it may be observed that whether we adopt the corpuscular theory of light, according to which the molecules of light are supposed to be endowed with attractive and repulsive forces, to have poles to balance themselves about their centres of gravity, and to possess other physical properties, or adopt the undulatory theory, the periods and spaces just given have a real existence.

It is not unreasonable to suppose that the heat rays, and chemical, or actinic, rays, which accompany the luminous rays in the solar beam, are endowed with properties analogous to those of the luminous rays, and possess qualities no less wonderful.

*Inflexion or Diffraction of Light.*—The property of light called inflexion, or diffraction, was first discovered

by Grimaldi in 1665. Since that time the subject has received a good deal of attention from many eminent philosophers, but it is to M. Fresnel that we are indebted for the most successful investigation of the phenomena.

If the rays of light diverging from a luminous point  $F$  (Fig 42) fall upon an opaque object  $AB$ , all those rays included within the angle  $AFB$  will be intersected, so that a screen held at  $CD$  will receive none of these rays. If we produce the lines  $FA$  and  $FB$  to  $A'$  and  $B'$ , they will include upon the screen those spaces which would have been illuminated by the rays proceeding from  $F$ , which are stopped by the opaque body  $AB$ .

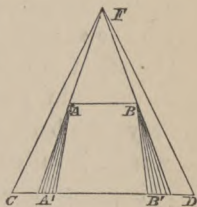


Fig. 42.

All the rays included in the angles  $AFC$  and  $BFD$  will proceed uninterrupted, and will fall upon the screen. If these rays suffered no change of direction, they would illuminate those portions of the screen included between  $c$  and  $A'$ , and  $D$  and  $B'$ . There would by this means be a well-defined shadow of the object,  $AB$ , formed upon the screen at  $A'B'$ , and the rest of the screen would be illuminated in the same manner as it would have been if the opaque body,  $AB$ , had not been present.

It is found by experiment that no such exact and well-defined shadow of the opaque object would be formed upon the screen. The outline of the space which would limit an exact and geometrical shadow of  $AB$  being determined, it is found that within this space light will enter, and that outside this space the illumination is not the same as it would have been if the object,  $AB$ , had not been interposed.

Hence it is inferred that the rays of light which pass

the edges of the opaque object do not proceed in the same straight lines,  $AA'$  and  $BB'$ , in which they would have proceeded if the opaque object was not present. The edge of the shadow is not a well-defined line, separating the illuminated from the dark part of the screen, but a line of gradually-decreasing brilliancy from the illuminated part of the screen to that in which the shadow becomes decided.

The effect produced by the edges of an opaque body upon the light passing in contact with them, by which the rays are bent out of their course, either inwards or outwards, is called *inflection* or *diffraction*.

This phenomenon is considered as a consequence of the general property of undulation. When the system of waves propagated round  $F$  as a centre encounters the obstacles  $AB$ , subsidiary systems of undulation will be formed round  $A$  and  $B$  respectively as centres, and will be propagated from those points independently of, and simultaneously with, the original system of waves whose centre is  $F$ , and which will also proceed towards  $CA'$  and  $DB'$ . In a certain space round the lines  $AA'$  and  $BB'$ , along which the rays, grazing the edge of the opaque body, would have proceeded, the two systems of undulation will intersect each other and produce the phenomena of interference.

*The Law of Interference.*—If two pencils of light, radiating from two points close to one another, fall upon the same spot of a piece of paper, in which case they may be said to interfere with one another, for if the paper were removed they would cross one another at that point, then if the lengths of their paths, or the distances between the paper and the two radiant points are the same, they will form a bright spot or fringe of light, having an intensity greater than that which

would have been produced by either pencil alone. Now it is found that when there is a certain difference between the lengths of their paths, a bright fringe is produced exactly similar to what is produced when their lengths are equal. Let us represent this difference by the letter  $d$ , then similar bright spots or fringes will be formed when the differences in the lengths of the paths are  $2d$ ,  $3d$ ,  $4d$ ,  $5d$ , and so on. But what is very remarkable, it is clearly proved that if the pencils of light interfere at intermediate points, or at those points in their paths when the differences in the lengths of the paths are half  $d$ , one-and-a-half  $d$ , two-and-a-half  $d$ , three-and-a-half  $d$ , and so on, then instead of adding to one another's intensity, the two pencils of light destroy each other, and produce a black spot or fringe.

The quantity  $d$ , or the difference in the length of the paths at which the interfering pencils of light either destroy one another or unite their effects, that is, at which they produce the black and light fringes, is also the *breadth*, or as it is sometimes called the *length* of an *undulation*, or a *wave of light*. M. Fraunhofer found the value of  $d$  for the different colours of the spectrum to be nearly the same as those found by Dr. Young, which are given in the first column of the table in page 95.

Still more recently M. Fresnel, by some carefully conducted experiments, arrived at nearly the same results.

Some important practical consequences follow from the finding of the value or length of  $d$ , among which are the following:—When we consider how glass is ground and polished, its surface cannot be mathematically correct; but as long as its inequalities, in reference to their distance from each other, are less than the length  $d$ , they will not be detrimental either to the light which is transmitted, or that which is reflected,

and no colours of any kind can be produced in them. It would likewise be impossible by any means to render inequalities of such a size visible.

*The Smallest Magnitude visible by a Microscope.*—If any object whose diameter is equal to  $d$  consists of more than two parts, it cannot be recognised as consisting of more than two parts. In red light the limit of microscopic vision is the thirteen-millionth part of an English inch, and in violet light the eight-millionth part of an English inch.

*Combined Effects of Inflexion and Interference.*—If an opaque body,  $AB$  (Fig. 43), be very small, and the focus  $F$  be a considerable distance from it, the two pencils formed by inflexion, of which  $A$  and  $B$  are the foci, will intersect each other as shown in the figure,

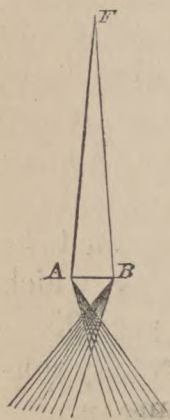


Fig. 43.

and in this case some curious phenomena will ensue. If the light be homogeneous, a bright line of light will be formed under the centre of the opaque object  $AB$ , outside which will be dark lines, and then bright and dark lines alternately. If the arrangement of these lines be examined, they will be found to vary in their relative distance with the quality of the light which radiates from the focus  $F$ . If the light radiating from such focus be compound light from the sun, then a series of coloured fringes will be formed.

*Examples of the Effects of Inflexion and Interference.*—A great variety of optical phenomena is produced by light passing the edges of small opaque objects, or small openings or slits made in the opaque plates. The principles, however, by which all these appearances are explained are the same.

If a fine wire or sewing-needle be held close to one eye, the other eye being closed, and be looked at so as to be projected upon the light of a window or a white screen, several needles will be seen.

If the eye be directed in a dark room to a narrow slit in the window shutter by which light is admitted, several slits will be seen separated by dark bands.

If a piece of card, having a narrow incision made in it, be held between the eye and a candle, a series of slits will be seen parallel to each other, exhibiting the colours of the spectrum. The same appearance may be produced with increased effect by looking through the slit at the sunlight admitted through an opening in the window-shutter.

*Thin Transparent Plates.*—When light passes from any transparent medium to another of different density, a part of it is reflected from their common surface, and a part only transmitted. Thus, when light passing through air is incident upon the surface of glass, a certain part of it is reflected from such surface, but the greater part enters it. When that portion which enters the glass arrives at the second surface, which separates the glass from the air, on the other side, a like effect ensues, a portion of the light is reflected from the second surface, the greater part, however, penetrating it, and passing into the air. Hence there are two systems of reflected rays—one reflected from the first surface of the glass, and the other by the second surface. The first system is reflected back immediately into the air, the second is thrown back into the glass, and must pass through the first surface of the glass before it returns into the air. If the two surfaces which thus successively reflect a portion of the light which passes through the transparent medium be very close together, and if they

be not precisely parallel, the reflected rays will intersect each other and produce the phenomena of interference.

*Iridescence of Mother-of-Pearl, Soap-bubbles, Feathers, &c.*—Hence arise the curious and beautiful appearances of iridescence which are seen whenever transparent substances are exhibited in sufficiently thin plates or laminæ, the prismatic colours that are seen in the scales of fishes, in spirit of wine spread in thin films on dark surfaces, in oil thinly diffused over the surface of water, and the thin laminæ of crystals and soap-bubbles, and glass bubbles blown to extreme tenuity, in the laminæ of mother-of-pearl, in the wings of insects, and feathers of birds.

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## CHAPTER XIII.

### DOUBLE REFRACTION, AND POLARISATION OF LIGHT.

WHEN treating of the refraction of light, in preceding chapters, through different media, it has been supposed that the refracting medium had the same density and structure in every part of it. This, however, is not always the case. There are two classes of transparent substances, which present optical phenomena depending on certain physical properties inherent in the constitution of each class of substances. When bodies such as gases, fluids, certain transparent solids, such as glass slowly and equally cooled, crystallised bodies, the form of whose primitive crystal is the *cube*, the *regular octohedron*, and the *rhomboidal dodecahedron*, have the same temperature and density, and are not subject to any pressure, light incident upon any single plane surface will be refracted according to the law explained in Chap. II.

In almost all other bodies, including crystallised

minerals not having the primitive forms above mentioned; animal substances, such as horn, shells, bones, lenses of animals; vegetable substances, such as certain leaves, stalks, and seeds; and artificial bodies, such as resins, gums, jellies, glasses quickly and unequally cooled, and solid bodies having unequal density either from unequal temperature or unequal pressure, a ray or pencil of light incident upon their surfaces will be refracted into *two different rays* or pencils, differently inclined to one another, according to the nature and state of the substance, or medium, and to the direction in which the ray or pencil is incident.

This property of *double refraction* was first observed in a transparent mineral substance called *Iceland spar*, *calcareous spar*, or *carbonate of lime*, which is composed of 56 parts of lime, and 44 of carbonic acid. In crystallising it generally assumes the form of a rhomb, such as that represented in Fig. 44, a solid bounded by six equal and rhomboidal surfaces, whose sides are parallel, and whose angles  $BAC$ ,  $ACD$  are  $101^{\circ} 55'$  and  $78^{\circ} 5'$ . The inclination of any face  $ABDC$  to any of the adjacent faces that meet at  $A$  is  $105^{\circ} 5'$ , and to any of the faces that meet at  $x$ ,  $74^{\circ} 55'$ . The line  $Ax$ , called the axis of the rhomb or of the crystal, is equally inclined to each of the six faces at an angle of  $45^{\circ} 23'$ . The angle formed by any of the three edges that meet at  $A$ , or of the three that meet at  $x$ , with the axis is  $66^{\circ} 44' 46''$ , and the angles between any of the six edges and the faces are  $113^{\circ} 15' 14''$  and  $66^{\circ} 44' 46''$ .

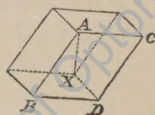


Fig. 44.

If we take a rhomb of Iceland spar, like Fig. 45, with well-polished faces, and each of its edges at least an inch long, and place one of its faces upon a sheet of

paper having a black line,  $LN$ , drawn upon it; if we then place the eye at  $R$ , and look through the upper surface of the figure, we shall probably see the line  $LN$  double, but if it be not so, by turning the crystal a little round it will become double, and two lines,  $LN, ln$ , will then be distinctly visible, and by turning the

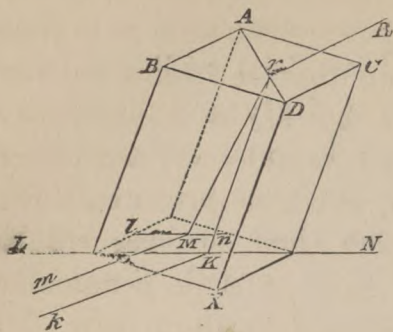


Fig. 45.

crystal round, keeping the same side on the paper, the two lines will coincide with one another, and form only one at two opposite points during a whole revolution of the crystal; and at two other opposite points, nearly at right angles to the former, the lines will be at their greatest distance from one another.

If a black spot be placed at  $K$ , the spot will appear double, as at  $K$  and  $M$ , to an eye placed at  $R$ ; and by turning the crystal round as before, the two images will be seen to revolve, as it were, around each other, excepting at the points where they coincide.

Let a ray or pencil of light,  $Rr$ , be now supposed to fall upon the surface of the crystalline rhomb at  $r$ , it will be refracted by that surface into two rays or pencils,  $rK, rM$ , each of which will be again refracted at the points  $K$  and  $M$  of the second surface, and will then move in the directions  $Kk, Mm$ , parallel to one another and to the incident ray or pencil  $Rr$ , which has thus been *doubly refracted*.

If we now measure the angle of refraction of the ray or pencil  $rK$  corresponding to different angles of incidence, we shall find that when the ray or pencil falls perpendicularly on the first surface of the crystal, it

suffers no refraction, but passes straight through the crystal in one unbroken line; that at all other angles of incidence the sine of the angle of refraction is to that of incidence as 1 to 1.654; and that the refracted ray is always in the same plane as that of the incident ray. Thus it appears that the ray  $r\kappa$  is refracted according to the *ordinary law of refraction*, which has been explained in Chap. II. If we proceed in the same way to measure the ray  $r\mu$ , we shall find that at a perpendicular incidence, the angle of refraction, instead of being  $0^\circ$ , is actually  $6^\circ 12'$ ; that at other incidences the angle of refraction is not such as to follow the constant ratio of the sines, and that it lies entirely out of the plane of incidence. It thus appears that the ray or pencil  $r\mu$  is refracted according to some *extraordinary law*.

*Axis of Double Refraction.*—If  $Rr$  be incident in various directions, either on the natural faces of the rhomb, or on faces cut and polished artificially, we shall find that in Iceland spar there is one direction,  $Ax$ , along which, if the refracted pencil passes, it does not suffer double refraction. In other crystals there are two such directions forming an angle with each other. In the former case the crystal is said to have one axis of double refraction, and in the latter case two axes of double refraction.

It is found that in some crystals the extraordinary ray is refracted towards the axis  $Ax$ , while in others it is refracted from that axis. In the first case the axis is called a *positive axis of double refraction*, and in the second case a *negative axis of double refraction*.

In a great variety of other crystals two axes of double refraction are found, whilst in others still innumerable axes of double refraction have been discovered. Among this last-mentioned class analcime is found.

*On Substances with Circular Double Refraction.*—The following are some of the substances which possess the remarkable property of producing *positive*, or right-handed circular double refraction, viz., certain specimens of rock crystal, camphor, oil of turpentine; other substances, such as concentrated syrup of sugar and essential oil of lemon, produce *negative*, or left-handed circular double refraction.

The limits of a work of this nature preclude the possibility of entering fully into the consideration of these curious phenomena.

*Polarisation of Light.*—If a ray of light be reflected from the surface of a body under certain special conditions, or transmitted through certain transparent crystals, it suffers a remarkable change in its properties, so that it will no longer be reflected and refracted as before. The effect thus produced upon it has been called *polarisation*, and the ray or rays of light thus affected are said to be *polarised*, as it is found that the sides of the ray which lie at right angles to each other possess contrary physical properties, while the sides of a ray of common light, whether of the sun, a candle, or any burning or self-luminous body, possess the same physical properties.

By way of illustration we may compare a ray of common light to a round rod or wire of uniform polish

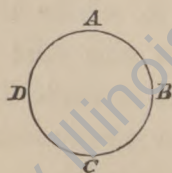


Fig. 46.

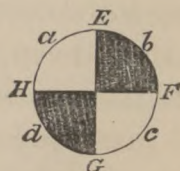


Fig. 47.

and uniformly bright, while a ray of polarised light may be compared to a similar wire, two of whose

opposite sides are rough and black, while the other opposite sides at right angles to these are polished and bright. Thus if  $A B C D$  (Fig. 46) be a section of the former, the entire circumference is bright and polished, and if  $E F G H$  (Fig. 47) be a section of the latter, the sides  $a$  and  $c$  will be bright and polished, while the sides  $b$  and  $d$  will be black and rough.

If we cause a ray of common light to fall upon a rhomb of Iceland spar, as in Fig. 45, and examine the two rays,  $\kappa k$  and  $m m$ , formed by double refraction, we shall find that the rays have different properties on different sides; so that each of them differs from the ray of common light. The two rays,  $\kappa k$  and  $m m$ , are therefore said to be *polarised*, or to be rays of *polarised* light, because they have sides or *poles* of different properties, and planes passing through the poles are called *planes of polarisation*, because they have the same property, and one which no other plane passing through the ray possesses. If we cause the two polarised rays to be again united into one, we obtain light which has exactly the same properties as common light. Polarised light possesses numerous properties, curious, complicated, and useful. If we blacken a plate of glass on one side, so that when used as a reflector no light will be reflected from its second surface, such a plate will therefore reflect light only from the first surface; and if we cause a polarised ray to fall upon it at an angle of incidence of  $54^{\circ} 35'$ , so that the plate shall make with the ray an angle of  $35^{\circ} 25'$ , and if it be turned round the ray, so as to be presented successively on every side of it, still, however, forming the same angle with it, during this operation it will be observed that there is a certain direction of the plane of the angle of incidence at which no reflection will take place; the ray will be

absorbed, or extinguished, as it were, by the reflecting surface. The plane of incidence will have this direction in two opposite positions of the reflector.

Let the line  $bd$  (Fig. 47) represent this position of the plane of incidence: then  $b$  and  $d$  will be the two opposite sides of the ray, at which the reflector being presented will cause the ray to be extinguished. As the reflection is carried round from either of these positions respectively, so that the plane of the angle of incidence shall turn round the axis of the ray, reflection will begin to take place, and will increase in intensity until the plane of the angle of incidence takes a position such as  $ac$ , at right angles to  $bd$ , when the intensity of the reflection will be a maximum.

From this it is evident that when the reflector is so presented to the ray that the plane of the angle of incidence shall coincide with the plane of polarisation, the ray will be reflected with the greatest intensity, and that when the plane of the angle of incidence is at right angles to the plane of polarisation, no reflection takes place, and the ray is extinguished.

*Angle of Polarisation.*—If any other reflecting surface be used instead of glass, like effects would follow; only that the angle at which it would be necessary to present the reflecting surface to the ray would be different, each species of reflector having its own particular angle. This angle is called the *angle of polarisation*.

*Polariscopes.*—Instruments called polariscopes, adapted for the experimental illustration of the phenomena of polarisation, have been constructed in various forms. For the purpose of elementary explanation, one of the most convenient is represented in Fig. 48. In the figure  $AB$  is a brass tube, like that of a telescope, along the axis of which the polarised pencil, or ray, to be

submitted to examination is transmitted; *c* is a short tube, capable of being inserted, after the manner of telescopic tubes, in the main tube at *A*. This tube *c* carries a plane reflector, *D*, of the blackened glass already described, which is capable of being turned on

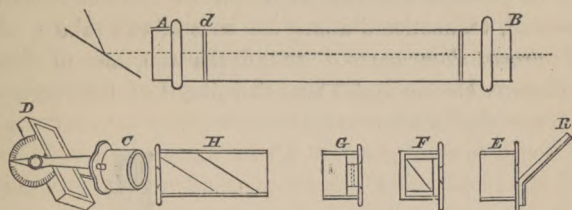


Fig. 48.

pivots, and is supplied with a double scale and index, by which the angle it makes with the axis of the tube can be regulated at pleasure. By turning the tube *c* round its axis, the plane of the reflector *D* may be presented successively on every side of the axis of the main tube.

In the tube at *d* a diaphragm is fixed, having a circular hole in its centre to limit the magnitude of the transmitted pencil of light. The pieces *e*, *f*, *g*, and *h* are each capable of being inserted in the end *B* of the tube, and of being turned round in the same manner as already described with respect to the piece *c* inserted at the end *A*. The short tube *e* carries a plane reflector *R*, similar to that just described, which is capable of being adjusted at any desired angle with the axis of the tube. The tube *f* contains a double refracting prism; the tube *g* contains a thin disc of tourmaline with parallel faces, so cut that the optic axis is parallel to these faces; and the tube *h* contains a bundle of plates of glass, with parallel surfaces placed in contact with

each other, and obliquely inclined to the axis of the tube.

All these pieces can be separately inserted in the tube A B, and turned round its axis, so that the reflector R, or the prism, or the tourmaline G, or the plates H, may be presented in succession on all sides of the ray, or pencil, transmitted along the axis of the tube A B.

*Improved Polariscopes.*—This apparatus, manufactured by Messrs. Horne and Thornthwaite, London, consists

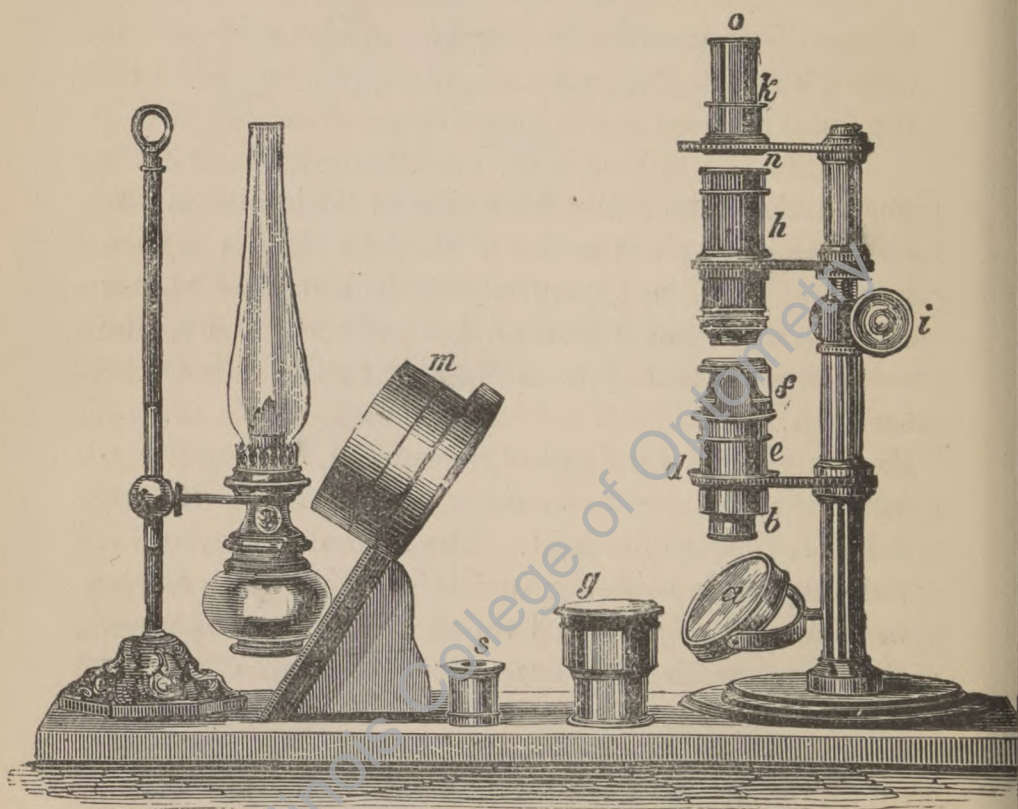


Fig. 48a.

of a tripod base, Fig. 48a, from which rises a stout pillar, forming the support of the whole. A mirror, *a*, near the base serves to direct the rays of light upwards through the various systems of lenses; immediately

above the mirror will be found the achromatised tourmaline, turning in its cell at *b*. Into the stage *d* fits the condensing lens *e*, and over that the crystal support *f*. When *e* and *f* are removed, the single condenser *g* also fits on the stage *d*. The telescope portion *h* can be raised or depressed by turning the pinion handle *i*; the analyser is at *k*, and admits of being rotated when necessary. The condenser *m* serves to direct the light, in a concentrated state, on the mirror *a*.

To use this polariscope for viewing rings in crystals, arrange it as shown in the figure, allowing about seven inches between the lenses *m* and the mirror, and bring the lamp as close to the lenses as possible.

Incline the mirror *a* so that the light shall be reflected upwards through *e* and *h* to the eye at *o*; but, however powerful the light may be that is reflected into *b*, *e*, and *h*, not a ray will reach the eye if the axis of the tourmaline at *b* and the Nicol's prism at *k* are in certain relations to one another. It is therefore necessary when testing the illumination to rotate the eye-piece until the light passes freely, and then incline the mirror, and alter the position of the foot, until the field of view is brilliantly illuminated; when this is the case the eye-piece is turned until the greatest possible amount of light is stopped, and allowed to remain at that position. The crystal to be examined is placed on the crystal-holder *f*, and the telescopic portion *h* is depressed until the greatest sharpness of the rings and illumination of the field take place; but as the position of the polariser, or tourmaline *b*, the analyser *k*, and the crystal must bear a certain relation to each other to gain the full beauty of colour, it is advisable to rotate the crystal until the maximum brilliancy is obtained.

Polarisation is induced in light by reflection, when

the angle of incidence upon any surface separating two media is such that the trigonometrical tangent of the angle is equal to the index of refraction corresponding to the media.

*Polarisation by Absorption.*—Crystals, such as agate, have the effect of intersecting one of the two polarised rays which constitute common light, and of transmitting the other. If a ray of common light be transmitted through a plate of agate, one of the polarised rays will be converted into nebulous light in one position of the crystal, and the other in another position, so that one of the polarised rays will be transmitted in each case.

*Utility of Polarised Light.*—A great variety of very beautiful and interesting phenomena is exhibited by transmitting polarised light through crystals and other bodies; and Sir David Brewster has shown that if two crystals have grown together with their axes inclined to one another, and if we cut a plate out of these united crystals so that the eye cannot distinguish it from a plate cut out of a single crystal, the exposure of such a crystal to polarised light will instantly detect its composite nature, and will exhibit to the eye the very line of junction. This will be obvious upon considering that the polarised ray has different inclinations to the axis of each crystal, and will therefore produce different tints at these different inclinations. Hence the examination of a body in polarised light furnishes us with a new method of discovering structures which cannot be detected by the microscope, or any other method of observation.

*Analysis of Sugar by Polarised Light.*—It is well known that sugar can be manufactured from various vegetable productions, such as the sugar-cane, the

grape, and most kinds of fruit, beet, carrots, the maple-tree, &c. By subjecting these several substances to chemical analysis they present no distinguishing characteristics; they give precisely the same constituents. Not so, however, when submitted to the test of polarised light. If, for example, sugar made from the grape be dissolved in water, the solution will be found to have left-handed polarisation, while the sugar produced from the sugar-cane has right-handed polarisation. In experiments on such liquids sensible effects can only be obtained by transmitting the polarised light through columns about ten inches in length.

*Polarising Saccharometer.*—M. Dubosch has invented an instrument called “polarising saccharometer,” by which the sugar refiner, or any other person interested in the manufacture or commercial value of sugar, is enabled to ascertain in half an hour, or less, the exact amount of crystallised sugar there is in a given sample, as compared with the quantity of non-crystallisable, or what is commonly called treacle, or syrup. This instrument is considered so accurate for the purpose for which it was intended, that the French Government has adopted it to determine the value of raw sugars imported into the country, and the customs duties are levied upon the results given by this instrument. The duty levied in France upon the manufacture of sugar from the beet is also based upon the results obtained by the same instrument.

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## CHAPTER XIV.

### THE EYE.

THE human eye—of which a front view is given in Fig. 49, and a vertical section in Fig. 50—is nearly of a globular form, with a slight projection in front. The

eyeball consists of four coats or membranes—namely, the sclerotic coat, the choroid coat, the cornea, and the retina; and these coats enclose three transparent fluids or humours—the aqueous humour, the vitreous humour, and the crystalline humour, or, as it is sometimes called, the crystalline lens.

The *Sclerotic Coat*, *aaa*, or the outside coat, upon which the maintenance of the form of the eye chiefly depends, is a strong, opaque, tough membrane, composed of bundles of strong white fibres, interlacing each other in all directions. This membrane covers about four-fifths of the external surface of the eyeball; leaving, however, two circular openings—a large one, in front, which is covered by a transparent concavo-convex piece of nearly uniform thickness, called the cornea; and a smaller one, behind, at the entrance of a nerve called the optic nerve, which, proceeding backwards and upwards, and passing through holes in the skull, terminates in the brain. It is by this nerve that the impressions made by external objects on the organ of vision are conveyed to the brain. The muscles which give motion to the eyeball are attached to the sclerotic coat, which constitutes the white of the eye.

The *Choroid Coat* is a delicate membrane, lining the inner surface of the sclerotic, and covered on its inner surface, generally, with a black substance. In some people this substance is white, in consequence of which they are enabled to see pretty well in the dark, but imperfectly in the light.

The *Cornea*, *bb* (Fig. 50), is an exceedingly tough membrane. It is closely united at its edge with the corresponding edge of the sclerotica. It is slightly elliptical in its form, its horizontal being rather longer than its vertical diameter. Its external surface is more convex

than that of the sclerotica, so that it forms a segment of a sphere, smaller than that of the general surface of the eyeball. It therefore projects outwards in front of the eye, making the axis of the eye, which passes through its centre, a little longer than the diameter, which is at right angles to it, or cuts it square across the middle. The cornea being of nearly uniform thickness, the concavity of its inner surface corresponds with the convexity of its outer, and gives the whole the form of a common watch-glass, or a concavo-convex lens whose surfaces have equal radii.

*The Retina.*—Within the choroid, and close to its black substance, lies the retina, *rrrr* (Fig. 50), which is the innermost coat of all. It is a delicate, reticulated, and perfectly transparent membrane, formed by the expansion of the optic nerve over the chief part of the internal surface of the eyeball. It is spread over nearly all the back and side parts of the surface, and terminates near the margin of the frontal opening covered by the cornea, already described. At the extremity of the axis of the eye, in a line passing through the centre of the cornea, and perpendicular to its surface, there is a small hole with a yellow margin, called the *foramen centrale*, which, notwithstanding its name, is not a real opening, but only a transparent spot, free of the soft pulpy matter of which the retina is composed.

*Iris.*—In looking through the cornea from without, we perceive a flat, circular membrane, *cc* (Fig. 49), within, called the iris, which is grey, hazel, blue, or black, and divides the fore part of the eye—or that part between the crystalline lens and the cornea—into two very unequal parts. In the centre of it there is a circular opening, called the pupil, which expands when a small portion of light enters the eye, and contracts

when a great quantity of light enters. The two parts into which the iris divides the eye are called the “anterior” and the “posterior” chambers.

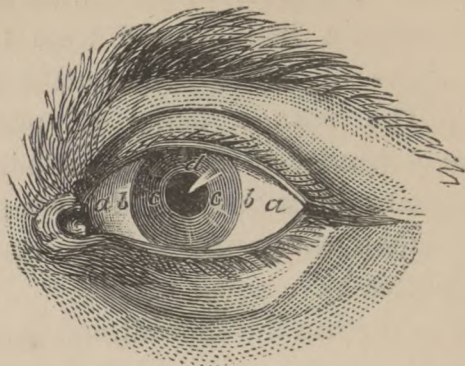


Fig. 49

The *Pupil* is the space through which the light, received through the cornea, is transmitted to the

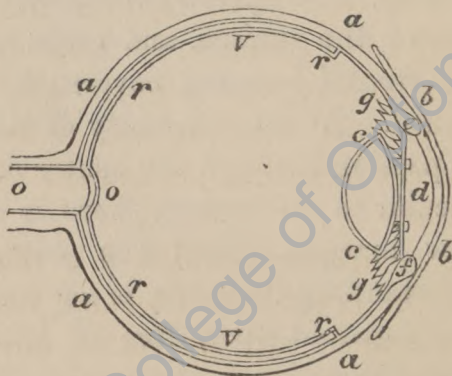


Fig. 50.

crystalline lens. By this means a pencil of rays is admitted to the crystalline lens, whose external limits are determined by the circumference of the pupil.

The posterior or back surface of the iris is covered by a black substance, or pigment, contained in a thin transparent membrane, called the uvea.

The *Crystalline Lens*, *c c* (Fig. 50), is a denser substance

than either the aqueous or the vitreous humour. It is suspended in a transparent bag, or capsule, by what are called the *ciliary processes*, *gg* (Fig. 50), which are attached to every part of the margin or circumference of the capsule. As the frontal opening of the sclerotica is closed by the cornea, that of the choroid, which corresponds with it in position, is closed by the crystalline lens. This lens is what is called in optical phraseology an unequal double-convex—the lens being more convex behind than before; the radius of its anterior or front surface being 0.30 of an inch, and that of its posterior or back surface 0.22 of an inch. The lens increases in density from its circumference to its centre.

*The Aqueous Humour.*—That part of the eye between the cornea and the crystalline is filled with a transparent liquid, called the aqueous humour, which, as its name implies, is a watery fluid, holding in solution very minute quantities of albumen, or a substance the same as the white of an egg, and common salt. The aqueous humour is separated from the cornea by an extremely thin, transparent membrane, called the *membrane of the aqueous humour*.

*The Vitreous Humour*, which fills that part of the eye between the crystalline lens and the retina, is not in immediate contact with the retina, but is enclosed in a fine, transparent membrane, called the *hyaloid*.

*Eyelids—Conjunctiva.*—The eyelids are not in immediate contact with the sclerotica or the cornea. A fine membrane, called the conjunctiva, which lines the inner surface of the eyelids, is carried over the fore part of the sclerotica, and over the front surface of the cornea.

*Eyebrows.*—The eyebrows across the projecting part of the forehead catch the sweat descending from above,

and prevent it from falling on the eyes, and aid in shading the eyes from too intense light from above. The eyelids may be considered movable screens, made so as to cover the eye, or leave it exposed, as occasion may require.

Glands are provided, by which all the parts that move in contact with each other are kept constantly lubricated.

*Dimensions of the Eye.*—The following are the principal dimensions of the eye:—

	Inch.
Radius of sclerotic coating . . . . .	0.39 to 0.43
„ cornea . . . . .	0.28 „ 0.32
External diameter of iris . . . . .	0.43 „ 0.47
Diameter of pupil . . . . .	0.12 „ 0.28
Thickness of cornea . . . . .	0.04
Distance of pupil from centre of cornea . . . . .	0.08
„ „ „ crystalline . . . . .	0.04
Radius of anterior surface of crystalline . . . . .	0.28 „ 0.39
„ posterior „ „ . . . . .	0.20 „ 0.24
Diameter of crystalline . . . . .	0.39
Thickness „ . . . . .	0.20
Length of optic axis . . . . .	0.87 „ 0.95

Sir David Brewster states that the principal focal length of the crystalline lens is 1.73 inches.

The limits of the play of the eyeball are the following:—The optic axis moves in a horizontal plane through an angle of  $60^\circ$  towards the nose, and  $90^\circ$  outwards, giving an entire horizontal play of  $150^\circ$ . In a vertical direction, it is capable of turning through an angle of  $50^\circ$  upwards, and  $70^\circ$  downwards, being a total vertical play of  $120^\circ$ .

*Production of the Image on the Eye.*—Knowing the structure of the eye, it is easy to explain the effect produced within it by luminous objects placed before it.

If we suppose light proceeding from any luminous object, such as the sun, to fall upon that part of the

eyeball which is left uncovered by the open eyelids, the part of the light that falls upon the white of the eye is irregularly reflected, and renders visible that part of the eyeball. Those rays of light which fall upon the cornea pass through it. The exterior rays fall upon the iris, by which they are irregularly scattered, or reflected, and render it visible. The internal rays pass through the pupil, and are incident upon the crystalline, which, being transparent, is also penetrated by them, from which they pass through the vitreous humour, and finally reach the retina, upon which they produce an illuminated spot.

*On the Law of Visible Direction.*—When a ray of light falls upon the retina, and enables us to see the point of an object from which it proceeds, it becomes an interesting question to determine in what direction the object will be seen, reckoning from the point where it falls upon the retina. Let  $F$  be a point of the retina on which the image of a point of a distant object is formed by means of the crystalline lens, supposed to be  $LL$ . Now, the rays which form the image of the point at  $F$  fall upon the retina in all possible directions from  $LF$  to  $LF$ , and we know that the point  $F$  is seen in the direction of  $ECR$ . In the same manner, the points  $f, f'$  are seen somewhere in the directions  $f's, f't$ . These lines  $FR, f's, f't$ —which may be called the *lines of visible direction*—may either be those which pass through the centre,  $C$ , of the lens  $LL$ , or, in the case of the eye, through the centre of a lens equivalent to all the refractions employed in producing the image; or it may be the resultant of all the directions within the angles  $LF L, L f' L$ ; or it may be a line perpendicular to the retina at  $F, f, f'$ . In order to determine this point, let us look over the top of a card at the point of the

object whose image is at  $F$ , till the edge of the card is just about to hide it; or—what is the same thing—let us obstruct all the rays that pass through the pupil, excepting the uppermost  $RL$ ; we shall then find that the point whose image is at  $F$  is seen in the same

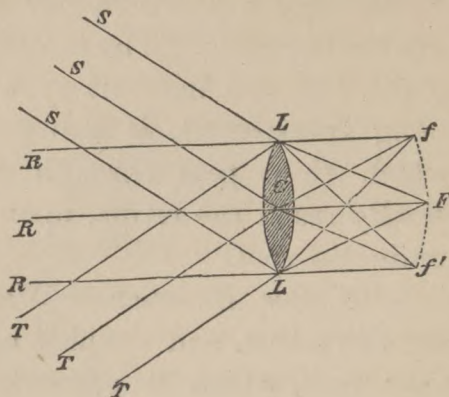


Fig. 51.

direction as when it was seen by all the rays  $LF$ ,  $CF$ ,  $LF$ . If we look beneath the card in a similar manner, so as to see the object by the lowermost ray  $RLF$ , we shall see it in the same direction. Hence it is manifest that the line of visible direction does not depend on the direction of the ray, but is always perpendicular to the retina. This important truth in the physiology of vision may be proved in another way. If we look at the sun over the top of a card, as before, so as to impress the eye with a permanent spectrum by means of rays,  $LF$ , falling obliquely on the retina, this spectrum will be seen along the axis of vision,  $FC$ . In like manner, if we press the eyeballs at any part where the retina is, we shall see the luminous impression which is produced in a direction perpendicular to the point of pressure; and if we make the pressure with the head of a pin, so as to press either obliquely or perpendicularly,

we shall find that the luminous spot has the same direction.

Now, as the interior eyeball is as nearly as possible a perfect sphere, lines perpendicular to the surface of the retina must all pass through one single point—namely, the centre of its spherical surface. This one point may be called the *centre of visible direction*, because every point of a visible object will be seen in the direction of a line drawn from this centre to the visible point. When we move the eyeball, by means of its own muscles, through its whole range of  $120^{\circ}$ , every point of an object within the area of the visible field, either of distinct or indistinct vision, remains absolutely fixed; and this arises from the immobility of the centre of visible direction, and, consequently, of the lines of visible direction joining that centre and every point in the visible field. Had the centre of visible direction been out of the centre of the eyeball, this perfect stability of vision could not have existed. If we press the eye with the finger, we alter the spherical form of the surface of the retina; we consequently alter the direction of lines perpendicular to it, and also the centre where these lines meet; so that the directions of visible objects should be changed by pressure, as we find them to be.

*Erect Vision from an Inverted Image.*—As the refractions which take place at the surface of the cornea, and at the surfaces of the crystalline lens, act exactly like those in a convex lens, in forming behind it an inverted image of an object—and as we know, from direct experiment, that an inverted image is formed on the retina—it had long been a problem how an inverted image produces an erect object. The law of visible direction, above explained and deduced from direct

experiment, removed at once every difficulty that beset the subject.

*The Eye Achromatic.*—We know by experience that the objects which we see are not edged with coloured fringes, as when we look through a prism—as is the case with most lenses. But if an object, by any means, be seen out of focus—that is, so that its image shall fall either before or behind the retina—the achromatism ceases, and coloured fringes become more or less apparent.

It is quite evident, from the forms and relative densities of the transparent humours which compose the eye, the achromatic combination of the lenses has not been produced by any accidental circumstances. The two menisci formed by the aqueous and vitreous humours, having the unequal double-convex crystalline placed between of greater density than either, and the two former differing from each other in density, appear to fulfil the conditions of achromatism in a most striking manner; and to this combination is due the freedom from colour in the image formed on the retina.

*The Eye Aplanatic.*—The peculiar combination of lenses in the eye renders it aplanatic—that is, exempts it from any sensible spherical aberration. If this were not the case, the images on the retina, and the perception of the objects producing them, would be more or less indistinct; which they are not.

It seems quite probable that the increasing density of the crystalline towards its centre has been given to it by the Divine Optician for the purpose of there giving it greater refractive power, so as to enable it to refract the central rays of light to the same focus as that of the external rays, and thus correct the spherical aberration.

*Conditions of Single Vision with both Eyes.*—The condition which produces identity of perception by both eyes at the same time is simply the identity of size, colour, brightness, form, and position of the optical pictures of the object formed on the two retinae. But, to understand what constitutes their identity of position, it is necessary that some point or line should be assigned, in reference to which the position of the picture is determined. This line must evidently be the optic axis, and the position of the two pictures will be identical if their corresponding points are similarly placed around the foramen centrale of the retina; that being the point, as already stated, through which the optic axis passes,—that is, if any point of one image fall upon the retina at the hundredth of an inch above or below the foramen centrale, the corresponding point of the other image must also fall at the hundredth of an inch above or below the foramen centrale of the other eye. In like manner, if the image of any point fall upon the retina of one eye at any given distance to the right or left of the foramen centrale, the image of the same point must fall at the same distance to the right or left, respectively, of the foramen centrale of the other eye.

*Inability of some Persons to distinguish Colours.*—Those persons who are unable to distinguish colours are generally capable of performing all the other delicate functions of vision. A shoemaker, named Harris, at Allonby, was unable from his infancy to distinguish the cherries of a cherry-tree from its leaves, in so far as colour was concerned. Two of his brothers were equally defective in this respect, and always mistook orange for grass-green, and light green for yellow. Harris himself could only distinguish black and white.

Mr. Scott, who describes his own case in the "Philosophical Transactions," mistook pink for pale blue, and a full red for a full green. All kinds of yellows and blues, except sky-blue, he could discern with great nicety. His father, his maternal uncle, one of his sisters, and her two sons, had all the same defect.

A tailor at Plymouth regarded the solar spectrum as consisting only of yellow and light blue; and he could distinguish with certainty only yellow, white, and green. He regarded indigo and Prussian blue as black.

Mr. Dugald Stewart, the eminent writer on metaphysics, could not perceive any difference in the colour of the scarlet fruit of the Siberian crab and that of its leaves.

Dr. Dalton was unable to distinguish blue from pink by daylight; and in the solar spectrum the red was scarcely visible to him, the rest of it appearing to consist of two colours.

Mr. Troughton, of the firm of Troughton and Sims, the eminent mathematical instrument makers, was capable of fully appreciating only blue and yellow colours.

In almost all these cases the different prismatic colours had the power of exciting the sensation of light, and giving a distinct vision of objects, excepting in the case of Dr. Dalton, who was said to be scarcely able to see the red end of the spectrum. Dr. Dalton endeavoured to explain his own case by supposing that the vitreous humour was blue, and therefore absorbed a great portion of the red and other adjoining rays. This opinion, however, was proved, by the *post-mortem* dissection of the eyes of that distinguished philosopher, to have been erroneous, as it appeared that the vitreous humour was perfectly transparent and colourless.

Sir John Herschel attributes the defects of Dr. Dalton's vision, and other defects of the same class, to a morbid state of the sensorium, or brain, by which it is rendered incapable of appreciating exactly those differences between rays upon which their colours depend.

Mr. Wortmann, of Geneva, has published an interesting memoir on this subject. The result of his researches is contained in the following summary:—Colour-blindness has been found only in individuals of the white race. Some of the colour-blind see only black and white, and some have the affection so slightly as only to confound approximating shades of blue and green in candle-light. There are more of the colour-blind than is generally believed. The female sex furnishes a small proportion. There are as many of the colour-blind with blue as with black eyes. Colour-blindness is not always hereditary. It does not always affect the males of the same family. It does not always commence at birth. The colour-blind do not judge as we do of complementary colours, or of the contrast of colours. Several of them are not sensible to the least refrangible or red rays. Colour-blindness does not arise from any diseased conformation of the eye, or any coloration of the humours of the eye or of the retina. Colour-blindness has its origin in the sensorium.

*Adaptation of the Eye to different Distances.*—The most distinguished philosophers have entertained different opinions with respect to the method by which the eye adapts itself to different distances. Sir David Brewster, to whom we are indebted for many valuable discoveries in optical science, states that in order to discover the cause of the adjustment, he made a series of experiments, from which he inferred—

1st. The contraction of the pupil, which necessarily takes place when the eye is adjusted to near objects, does not produce distinct vision by the diminution of the aperture, but by some other action which necessarily accompanies it.

2dly. That the eye adjusts itself to near objects by two actions; one of which is voluntary, depending wholly on the will, and the other involuntary, depending on the stimulus of light falling on the retina.

3rdly. That when the voluntary power of adjustment fails, the adjustment may still be effected by the involuntary stimulus of light.

The different opinions that are entertained by scientific men upon this question render it quite possible they may be all more or less wrong. I am strongly inclined to think the eye adapts itself to different distances by a sort of galvanic or electric action, induced in it by the stimulus of light proceeding from external objects; the force of this action depending upon the distance from which the light proceeds, the intensity of the light, &c. This opinion, to a great extent, is as yet not much better than a hypothesis. But there is a close analogy between this view of the question and the manner in which an electrician determines the distance at which a fault occurs in either an electric wire above the surface of the ground, or in a submarine cable. When a fault occurred in one of the Atlantic cables soon after it had been laid down, the electrician at Valentia, Ireland, ascertained by his electric apparatus the precise distance from Valentia at which the fault occurred, although that distance was nearly two thousand miles from him, the cable at the time lying in the bed of the ocean.

*The Size of Pictures on the Retina.*—There can scarcely

be anything more calculated to excite our wonder than the distinctness of our perception of visible objects, compared with the size of the picture on the retina, from which our perception is immediately derived.

If, with the naked eye, we look at the full moon on a clear night, we see distinctly the light and shade on its surface. The diameter of its picture on the retina is  $\frac{1}{230}$ th part of an inch, and the entire size of the space on the retina occupied by the image is  $\frac{1}{22900}$ th part of a square inch; yet within this small space we are able to perceive a great number of still more minute details. For example, we see forms of light and shade whose linear dimensions are only about  $\frac{1}{10}$ th part of the apparent diameter of the moon, and which therefore occupy upon the retina a space the area of which is less than  $\frac{1}{5,000,000}$ th part of a square inch.

## CHAPTER XV.

### ACCIDENTAL, OR COMPLEMENTARY COLOURS.

If we look steadily for some time at any brightly-coloured object, the eye becomes strongly impressed with that colour, and if we then suddenly look at a sheet of white paper, the paper does not appear white, or of the colour impressed by the object, but of a different colour, which is called the *accidental colour* of that with which the eye was impressed. If a bright red wafer be placed upon a sheet of white paper, and we steadily look at a mark in its centre, then if we turn the eye upon the white paper we shall see a circular *bluish-green* spot of the same size as the wafer. This *bluish green* is called the accidental colour of *red*.

If the preceding experiment be made with wafers of

different colours, we shall obtain *accidental colours*, or *ocular spectra*, as they are called, as follows:—

Colour of wafer.	Accidental colour.
Red . . . . .	Bluish green.
Orange . . . . .	Blue.
Yellow . . . . .	Indigo.
Green . . . . .	Violet, reddish.
Blue . . . . .	Orange-red.
Indigo . . . . .	Orange-yellow.
Violet . . . . .	Yellow-green.
Black . . . . .	White.
White . . . . .	Black.

In order to find the accidental colour of any colour in the spectrum, arrange the prismatic colours in a circle in their due proportions, then the accidental colour of any particular colour will be the colour exactly opposite that particular colour. For this reason they have been called *opposite* colours.

If the colour which impresses the eye be reduced to the same degree of intensity as the accidental colour, it will then be seen that one is the complement of the other, or what the other wants to make white light. Hence accidental colours have been called *complementary* colours.

Assuming the numerical value of white light to be 100, the proportional values of the three primary colours that compose it are, red 20, yellow 30, and blue 50. A compound of any two of these colours will, when added to the remaining one, complete the composition of white light, and is therefore called the complementary of that colour. For the same reason every primary colour may be considered as the complementary of that secondary composed of the other two. Thus, as has been already stated, red and green are complementaries of each other; yellow and purple or violet stand in the same relation, as do also blue and orange.

The following (Fig. 52) clearly illustrates the state-

ments. The three circles which intersect each other contain the primary colours, red, yellow, and blue. In the spaces where any two overlap, the secondary or complementary colours are produced, and where the whole three combine in the centre, there is white light. It will be observed that the complementary colours are opposite each other. The secondary colours are not of uniform tone in the solar spectrum, in consequence of the unequal proportions of the primaries which enter into their composition, but on each border partake more of the character of that primary which adjoins it.

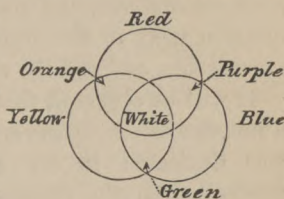


Fig. 52.

The combination of colours and gradation of tones of colour are clearly exhibited in Fig. 53. By this arrangement the complementary of any colour in a large number of colours can be seen at a glance. The primary colours,



Fig. 53.

red, yellow, and blue, are placed at the greatest distance from each other, whilst the secondaries, in their most perfect state, occupy intermediate positions; between

these and the primaries are placed modifications of both by each other (enclosed in braces in the figure), each being on its own side considered as the fundamental colour, and on the remote side as the modifier. For instance, in the mixtures of red and orange, in the division nearest the red, this is regarded as the predominant hue, and orange the modifier, whilst in the division next to the orange this colour is the fundamental one, and red the modifier.

It will be observed that the figure is subdivided into a number of concentric spaces—in the original, which was dedicated to Sir Joshua Reynolds, there are twenty, from the deepest tint in the centre, to the palest at the circumference—thus giving a range of 360 tints.

In Fig. 54 the secondary colours, orange, green, and



Fig. 54.

purple or violet, occupy the positions of the primaries in Fig. 53. In this arrangement we have upwards of 360 different tints, making with the former a comprehensive yet simple and intelligible scheme of more than 700 tints, showing at a glance the complementarity of each particular tint.

*Harmony of Colours in Art.*—Artists, whether in oil or water colours, obtain a ready reference to any particular colour, tint, or tone they may require, by the arrangement just explained. All persons engaged in the art of decoration, whether of buildings, furniture, or dress, will also find it invaluable in enabling them to select those colours which have a harmonious relation to each other, and which are therefore pleasing to all persons of cultivated taste and refinement.

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## CHAPTER XVI.

### OPTICAL INSTRUMENTS.

AMONG the great variety of optical instruments which have been invented, and which have conferred upon man such powers as enable him not only “to inspect a mite,” but “to comprehend the heavens,” there are none perhaps that have been of such real utility as spectacles. It is true that instruments more calculated to excite our wonder and astonishment have been invented; the telescope and the microscope disclose to us phenomena and laws which excite in our minds sentiments of the most exalted character, but though spectacles can lay no claim to anything of this kind, their beneficent influence is equally felt in the cottage of the peasant and in the palace of the monarch.

*Spectacles* consist of two glass lenses mounted in a frame so as to be conveniently supported before the eyes. The defects of vision which are remedied by spectacles are those called weak sight or long sight, and short sight. Weak sight or long sight arises from the convergent

power of the eye being too feeble ; that is, the rays of light proceeding from a distant object would be brought to a focus *behind the retina*, if the rays could pass through the back coats of the eye, instead of on the retina. The feeble convergent power of the eye may arise either from a defect in the quality of the humours, or in the form of the eye, or from both combined. Such defects are remedied by spectacles having convergent lenses, which assist the eye in bringing the light from external objects to a focus on the retina. Near sight, or short sight, arises from the convergent power of the eye being too strong ; that is, the rays of light proceeding from external objects are brought to a focus before they reach the retina. This excess of convergent power in the eye may be produced by the too great convexity of the cornea, or the crystalline lens, or the too great density of the aqueous and vitreous humours, or from both these causes combined. Near sight, or short sight, is remedied by spectacles having divergent lenses. When the eyes look straight forward the centres of the lenses should be in line with the optical axes of the eyes ; that is, the distances between the centres of the lenses should be precisely equal to the distance between the centres of the pupils.

*The Magic Lantern* is an instrument adapted for exhibiting pictures, painted on glass in transparent colours, on a large white cloth or screen, by means of magnifying lenses. It is shown in Fig. 55, where L is a lamp with a powerful Argand burner, or what is more brilliant, the oxyhydrogen light, the oxycalcium light, or, better still, the electric light. On one side of the lantern is a concave mirror, M N, whose vertex is opposite the centre of the light, which is placed in its focus. A tube, A B, containing a hemispherical lens, A, and a

convex lens, B, is fixed in the opposite side of the lantern. C D is a groove into which the glass pictures are slid; the middle of the picture should be in the axis of the tube. The light at L, increased by the light reflected from the mirror falling upon the lens A, is concentrated upon the picture in the slider, and this picture being in one of the conjugate foci of the lens B, an enlarged image of it will be represented on a white cloth, or on a screen of white paper, E F, placed perpendicularly some six or eight feet from the lantern. The distance of the lens B from the painted picture or slider

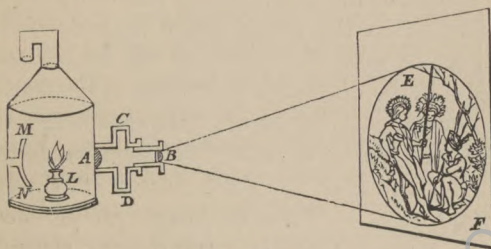


Fig. 55.

may be increased or decreased by pulling out or pushing in the tube B, so that a clear and distinct image may be formed on the screen of any size, and at any distance from the lantern within moderate limits. If the screen is made of fine muslin or tracing cloth, the image may be distinctly seen by an observer on the other side of the screen. As the image on the screen will be inverted in relation to the picture on the slider, it is necessary to turn the slider upside down, in order to have the image on the screen in an erect position.

In constructing the lantern, the concave mirror, M N, is sometimes left out, as an effect equally as good may be produced by simply bending a sheet of white paper

or pasteboard round the internal surface of the lantern. In order to prevent the lantern becoming over-heated, the body should be large. If oil should be burnt in the lamp as the illuminator, the best quality should be selected, so as to diminish the smoke and disagreeable odour. The glass chimney of the lamp should be as high as possible, and the wick large, and of cotton thread previously well dried. The wick should be evenly cut all round, and should project about one-quarter of an inch above the holder.

Before exhibiting the images on the screen the lantern should be adjusted. If the disc of light thrown by the lantern on the screen has a central dark spot, the distance between the lamp and the lenses must be increased; if the disc has a dark edge, the lamp must be brought nearer the lenses; if a dark shadow appears on the right-hand side of the disc, the lamp must be moved to the right; and if on the left-hand side, to the left.

*Phantasmagoria.*—When the images are produced by the magic lantern through a transparent screen, the exhibitor at the time being concealed from the spectators, may make the images vary in magnitude; first gradually increasing, and then gradually diminishing. This is accomplished by moving the lantern, which is mounted on wheels, gradually from and towards the screen, changing the focus during the motion, so as always to produce a distinct picture or image on the screen. If the tube of the lantern is first placed in contact with the screen, the image will then be very small, and the spectators, to whom the screen is almost invisible, as the room should be darkened, will imagine the image to be at a great distance from them. If the lantern be then moved back slowly from the screen, keeping all the time the focus adjusted, the image on

the screen will then be gradually enlarged, and the impression produced on the minds of the spectators will be, that the enlarged size is produced by the gradual approach of the image towards them; and so perfect is the delusion, that the increase of the magnitude of the image startles even persons who are well acquainted with the optical causes which produce this delusive effect. The image appears sometimes as if it would come in actual collision with the observer.

When the image thus appears to be brought close to the observer, it is made to retire gradually by moving the lantern towards the screen, the focus being kept constantly adjusted, which produces a gradual diminution of the image on the screen, and this is continued until the tube of the lantern comes up to the screen, when the image again seems lost as it were in the distance. At this moment the exhibitor changes the slider, a manœuvre which, when skilfully performed, will escape the notice of the observers. The new picture may then be exhibited in the same manner.

The word "phantasmagoria" is derived from the Greek words *phantasma*, "spectre," and *agoraomai*, "I meet."

*The Ghost*.—A phantasmagorical illusion called "The Ghost" has been exhibited during the last few years at the Polytechnic Institution, London, to large public assemblies. In this illusion two or more figures appear on a stage, and the spectators view them as real living actors. The spectators being situated in a distant, darkened, and elevated portion of the building, see on an illuminated stage two or more figures, but without being aware that one or more of them bear a visionary character. The peculiarity of this mode of exhibiting spectral appearances consists in associating a living figure with a merely visionary one, and yet the illusion

is so well sustained that the spectators distinguish no visible difference between the several actors, when properly managed, until the circumstances of the dramatic scene require the visionary figure to fade away, or pass through the walls of the apartment, or play any similar spectral part.

For this purpose an oblong chamber is divided into two equal parts by a vertical screen of thin glass, having a perfectly true surface. One of these parts is made the stage on which the acting takes place; its floor and three of its walls are solid, and the fourth is one entire glass screen; the ceiling must be made to open at different parts to let in light, and have suitable blinds to regulate the light and shade in which the actors perform. The chamber opposite, or facing the actors, is in reality a second stage for carrying out the spectral performances. It will now be obvious that the actor beneath the seats of the spectators can only be seen by reflection, and the trained actor on the opposite stage, knowing the precise situation of the reflection as seen by the spectators, performs accordingly.

Some startling effects may be produced illustrative of the illusive properties of optical apparatus constructed on the principle described. Thus figures placed before a white screen are so strongly reflected, that the spectator cannot divest his mind of their being the substance and not the shadow which he observes, particularly as he contrasts them with an adjacent solid figure. By placing two figures of corresponding form equidistant, one on each side of the glass mirror or screen, they appear as one, until one is moved; and if they differ in colour, as one blue and the other white, the effect is more remarkable. If a cabinet, box, or the like is placed one on each side of the mirror, until the image

of one exactly corresponds with the material figure of the other, then the spectator may see the visionary figure open a drawer or door, and remove and replace anything therein, and afterwards the solid figure repeat the same acts. If the reflection of an actor is thrown on a transparent screen it is invisible, but by gradually decreasing the light on the acting stage the spectral appearance will be as gradually developed until, apparently, it becomes a firm solid figure in all its proper costume, and acting in conformity to its designed character.\*

The arrangement of the apparatus will be understood by reference to Figs. 55*a* and 56, the former

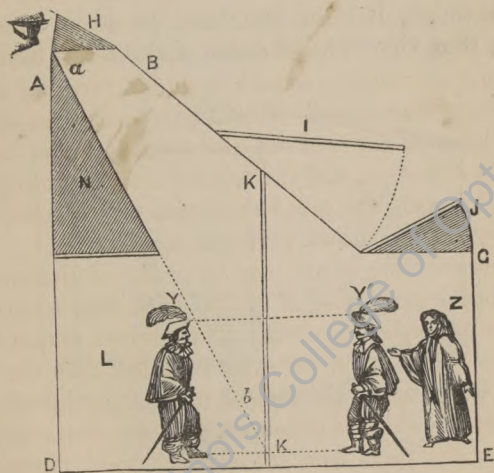


Fig. 55*a*.

being a vertical section, and the latter a plan. A B C D E is a box closed on all sides, but provided on one side

\* This apparatus is the invention of Henry Dircks, Esq., C.E. If the transparent mirror be inclined, objects in motion, such as a statue, picture, &c., placed before it, appear as if floating in the air.

with the door E, and on the other with the door G, hinged to the back, A D; and on the top of the box are the flapped openings, H I J; the interior of the box is divided centrally by the partition K K, made of a good, clear, and even-surfaced piece of thin patent plate glass, kept in its place within two side grooves; the box is thereby divided into two separate chambers, L and M, the latter having a ceiling or screen, N, to exclude any object therein from the direct view of the spectator, as shown by the line *a b*. If two figures be now introduced, one *y* the other *z*, and the eye of the spectator be fixed at A, he will observe two figures, one real, *z*, the other *y'*, the mere reflection of *y*. By this arrangement, it is evident that the plain, unsilvered glass, thus viewed at an angle of about  $45^\circ$ , has all the

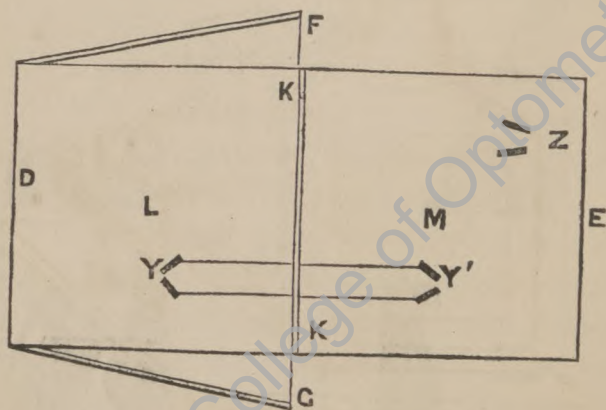


Fig. 56.

properties of a mirror, but owing to its transparency two figures are seen, possessing little or no distinguishable difference between them. Of course a person placed at *z* sees only the figure *y*; but as a piece of acting may, under proper arrangements of a suitable stage, approach the situation apparently occupied by *y'*, and

thus indicate to a spectator placed at A any pre-arranged dramatic scene, requiring  $z$  to be in correspondence with the visionary figure  $y'$ .

*Dissolving Views.*—The marvellous effects termed “dissolving views” are produced by placing two lanterns of equal power, so as to throw images of equal size on the same part of the screen. Fig. 56a represents the two lanterns, with the revolving fans in front of the tubes. The apparatus is so arranged that while the aperture of one lantern is open, so as to allow the picture or image produced by it to fall on the screen, the other is completely closed. When a change is

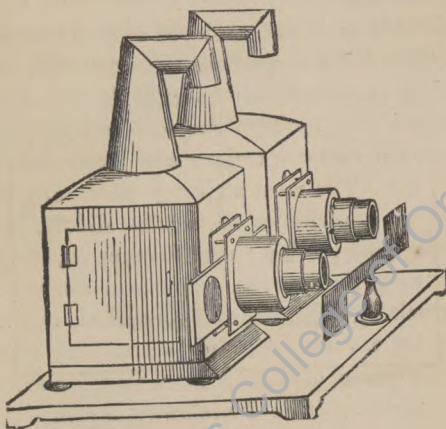


Fig. 56a.

desired, the turning of a handle moves the fans, and allows a portion of the picture, which before was stopped, to fall on the screen, whilst a corresponding part of the picture first exhibited is effaced. The continued turning of the handle causes a further blending of the two pictures or images, one seeming to recede,

and the other becoming clearer, until the one first shown is completely obliterated, and the other plainly visible on the screen. The slider which has been exhibited is now removed, and another substituted, and the dissolving effect is produced in exactly a similar manner as before, excepting that the handle must be turned the reverse way to the former one. The effect of two pictures or images of quite a different character merging one into another, and in so gradual a manner as to defy the eye to detect the change until it has actually taken place, is very astonishing, and renders the dissolving views a most attractive and pleasing exhibition.

The pictures or sliders employed must be finished with extreme care, and the smallest minutiae well executed, or, on being so enormously magnified, they would lose their proper effect. The subjects usually consist of landscapes, sea views, interiors and exteriors of public buildings, &c. The most striking effects are produced by exhibiting a series of *consecutive* sliders, such as a ship leaving port by day; night comes on, and the ship is seen by moonlight at sea. A storm approaches, the ship is struck by lightning and consumed, and the crew are saved by a raft. Another series may represent a summer landscape changing to a thunder-storm, with rain and lightning; this clears away, a rainbow is seen, and the series concludes by the summer scene being succeeded by winter, with trees, hills, houses, &c., covered with snow. Fig. 56*a* represents Messrs. Horne and Thornthwaite's Model Dissolving-View Apparatus, by which views are exhibited with clearness on an opaque or transparent screen eight feet in diameter, the illuminating power being powerful Argand lamps, or the oxycalcium light. It is readily set

in action, and is well adapted for schools and private families.

The oxycalcium light is produced by forcing a jet of oxygen gas obliquely through the flame of a spirit lamp, and placing a ball of lime so that the deflected flame may impinge on it. This light is superior to that of the best Argand lamp for illuminating the dissolving views, the phantasmagoria lantern, the microscope, or the polariscope, and is but little inferior in brilliancy to the oxyhydrogen light. The advantages the oxycalcium possesses over the oxyhydrogen are—greater economy of the first cost of the necessary apparatus; less trouble in the manufacture of the gas, and consequent diminished bulk of the gas bags, &c.; the total absence of danger in using it, even in the hands of the most inexperienced (as oxygen gas is not combustible or explosive); and the constancy of the light produced, no turning of the lime ball, or variation of the supply of gas or spirit, being required.

*Bi-unial Dissolving-View Apparatus.*—This apparatus, which is the most portable, simple, and efficient yet introduced, is adapted for the oxyhydrogen light. It consists of but one lantern instead of the usual combination of two. The lantern is usually made of mahogany, having two sets of lenses and their respective mountings attached to it, one above the other; and having in the interior two sets of the necessary fittings to produce two oxyhydrogen lights. The lenses require no adjusting to insure perfect coincidence of the two pictures on the screen, neither are there any fans required, as the dissolving effect is produced by stop-cocks attached to the burners.

*The Electric Light.*—The illumination of the magic lantern by either the oxycalcium or oxyhydrogen light

is surpassed in splendour by that of the electric light, which has been applied to the illumination of the magic lantern by M. Dubosc, the celebrated optician of Paris. The electric light is produced by bringing two pieces of charcoal, previously put in connection with the poles of a voltaic battery, nearly into contact; the current will then pass from one piece to the other, and cause them to become incandescent, when they will emit the most brilliant artificial light which has yet been produced. Means have been contrived by which a single electric light illuminates, at the same time, two lanterns, placed side by side for exhibition. This is done by placing the light between two reflectors, so inclined that each reflects it in the direction of the axis of one of the lanterns.

*Photographic Lenses or Objectives.*—The extensive application of photography to the arts of painting, sculpture, and architecture, to various useful arts, and to many scientific pursuits, has called into requisition the greatest skill of the scientific and practical optician in designing and manufacturing photographic lenses or objectives most suitable for the purposes to which they are applied. When the processes of Daguerre and Talbot were first given to the world, it was apprehended by many persons that the excellence and truthfulness of their delineations would cast into the shade the less correct representations of the portrait and the landscape painter. Instead of superseding the arts of design, photography supplies them with the most valuable materials—with scenes in life and facts in nature—without which art would remain comparatively unprogressive. Before the time of the inventions of Daguerre and Talbot, the minute and accurate delineation of nature was a task almost impossible, requiring an

amount of toil on the part of the artist which could hardly be repaid even when but slightly performed; but photography has furnished art with the most perfect means of arresting, in their most delicate and pleasing forms, every object, however minute, that can enter into the composition of a picture, enabling it, by the multiplication of life and thought, to tell more truth, without disturbing in the least its repose, nor impairing in any way the general effect.

The form of camera obscura and lens shown by Fig. 57 was that first used by the inventor, Baptista

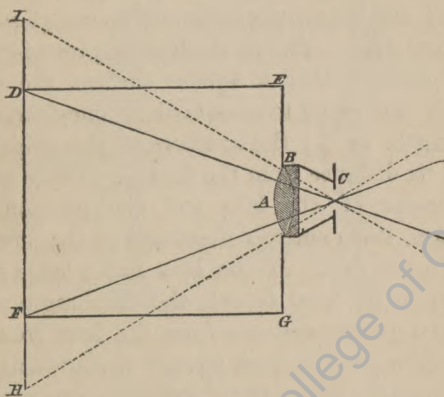


Fig. 57.

Porta. The achromatic plano-convex lens, A, was placed in a conical mounting of brass, B, furnished with a diaphragm, c, beyond which a circular plate slid, which served as a shutter. The aperture of the smallest diaphragm was about  $\frac{f}{30}$ . There were, besides, many others, the greatest of which had an aperture four times as great as that of the first,  $\frac{f}{15}$ , which could be used according to the intensity the image was intended to

have. The objective or lens was mounted on a camera,  $DEFG$ , of which the ground-glass,  $DF$ , was much smaller than the field,  $IH$ , which resulted from the distance between the lens  $A$ , and the diaphragm  $c$ , being too short. The objective therefore acted only at its central part, the light at the margin having been lost.

It was afterwards found out by opticians that the meniscus form, as represented by Fig. 57*a*, was preferable to the plano-convex, inasmuch as it gave, with equal focal length, a well-defined image of greater extent. The concave surface of flint-glass was towards the object, and the convex surface of crown-glass towards the ground-glass. The focal plane or ground-glass was sharply covered over a square surface, the diagonal of which was equal to one-third or one-fourth of the focal length, or  $\frac{f}{4}$ ; the aperture of the diagonal was  $\frac{f}{30}$ , and its distance from the lens  $\frac{f}{5}$ . With regard to the diameter of the lens and the position of the diaphragm, these entirely depended on the concavity of the flint-glass face. If the lens has a large diameter relatively to its focal length, the diaphragm must be placed at a greater distance from the lens, so that the ground-glass may be large enough to represent the size of the image for which the objective is constructed. If the radii of curvature of the lens or objective are properly chosen, the field is as flat as possible, but there is considerable distortion. If the diaphragm be moved nearer the lens, the field becomes less flat, but the distortion diminishes. In order to produce the greatest sharpness, a more concave face must be substituted for that of the existing flint-glass, or that towards the object. In all cases the spherical aberration is corrected by the aid of a small diaphragm of say  $\frac{f}{30}$ .

and the chromatic aberration by a proper selection of the flint and crown glasses; but it is of the first importance to reduce the spherical aberration to the least possible, as by this means very great perfection in the details of the photographic proof is obtained, which constitutes its sharpness. The greater the spherical aberration is, the smaller must be the diaphragm, to give the image that clear definition which is required, and, consequently, the longer must be the exposure to the light, as the intensity of the image depends upon the aperture of the diaphragm.

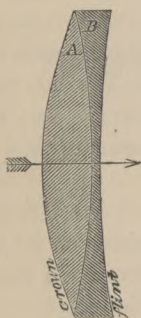


Fig. 57a.

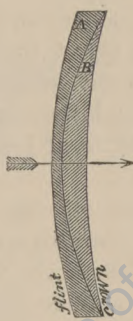


Fig. 58.

Mr. Grubb, of Dublin, some years ago obtained a patent for the form of objective shown in Fig. 58, in which the crown-glass lens B, of meniscus form, has the concave face towards the object to be reproduced. The divergent flint-glass lens A is cemented to the crown-glass lens, and has the same diameter. Its form is also a meniscus. This arrangement is therefore the reverse of the objective represented in Fig. 57a, in which the flint-glass B is turned towards the object, whilst

in this it is the crown-glass. By this objective, the rays parallel to the axis are achromatised; the focal length of oblique rays is increased, thereby giving a flat field, and of much greater extent than that of the objective represented in Fig. 57*a*; the spherical aberration is much less, and therefore permits the use of larger diaphragms, by which the proofs are rendered more brilliant, and more relief is obtained.

It thus appears there are two kinds of single objectives. In one, the flint-glass face is towards the object to be reproduced; in the other, the crown-glass face is towards the object. In both the meniscus form has been adopted; and in both the concave face is turned towards the object to be reproduced, and the convex face towards the ground-glass. The advantages possessed by the latter over the former are, less distortion, a shorter focal length, greater rapidity, and less bulk.

The inferior objective is still generally adopted by French and German opticians, some of whom are beginning to adopt the better form. In England and America the superior form is adopted.

The form of single objective, a section of which is shown in Fig. 59, has been extensively adopted in England and America. *AB* is the flange which is attached to the camera; *CDEF* the cylindrical tube in which the objective, *LM*, is mounted. *GH* is the diaphragm, being a disc of brass, perforated with circular apertures of varying diameters, the centres of which are at equal distances from its centre of rotation. In order to substitute one aperture of the diaphragm for another, it is only necessary to press the finger on the exterior part, *G*, which causes it to revolve; a spring

presses on the disc, and catches by its extremity in shallow notches, so that a shock is felt when the centre of each aperture of the diaphragm corresponds with the axis of the objective.

*Mr. Dallmeyer's new Single Objective.*—In order to reduce the distortion to a minimum, and to make the objective include a large angle, Mr. Dallmeyer, of London, the eminent optician, has given to the single objective the meniscus form (Fig. 59), and has placed

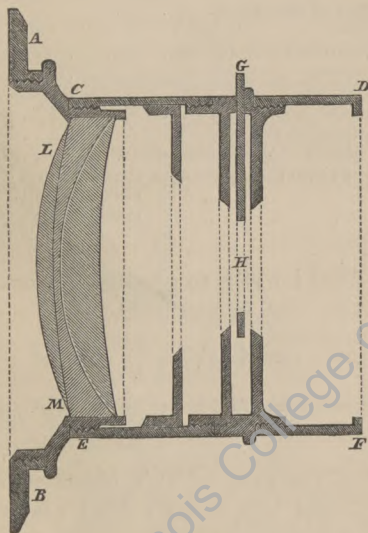


Fig. 59.

the diaphragm nearer the lens. In this objective, in addition to the two lenses—the one of crown-glass, the other of flint—Mr. Dallmeyer employs a third lens of crown-glass, of which the index of refrac-



is flatter than the older forms of single objective, and the image brighter; and, finally, that it is less in weight and bulk, and requires, on account of its short focal length, a much shorter camera, which the practical photographer will scarcely fail to appreciate.

*The Globe Objective.*—This objective consists of two equal achromatic convergent meniscuses, and so placed that the external surface of the lenses would, if continued till they meet, form a globe. Hence it has been called a globe-lens, or globe-objective.

Fig. 60 shows clearly how it is mounted. The two lenses, each enclosed in a ring, are fixed to the ends of a brass tube, having an expanding cone of brass, blackened on the inside, turned towards the object to be reproduced. On this cone a cap of pasteboard is fitted, which serves to close it. Midway between the lenses is

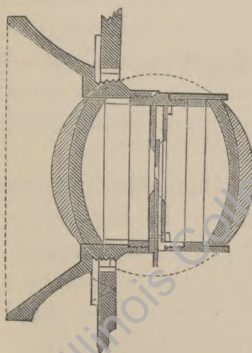


Fig. 60.

placed the diaphragm, which consists of a circular plate of brass, perforated by holes varying in diameter to regulate the light. The diaphragm is actuated in a similar manner to that in Mr. Dallmeyer's single ob-

jective (Fig. 59). The following are the numerical data:—

Radius of curvature of 1st surface of crown-glass . .	1,412
2nd   "                                  " . .	2,403
3rd   "                                  flint-glass . .	2,403
4th   "                                  " . .	1,620
Diameter of the lenses . . . . .	1,875
Thickness of the central part of meniscus . . . . .	231.5
Distance between the external surfaces along the axis . . . . .	2,824
Absolute focal length . . . . .	10,000
Aperture of the largest diaphragm $\frac{f}{36}$ . . . . .	277.7
"           smallest   " $\frac{f}{72}$ . . . . .	138.8
Density of crown-glass, 2.543 : Index of ref. 1.53.	
"           flint-glass 3.202 :           "           1.60.	

In order that the inner surfaces should be cleaned when necessary, the mounting unscrews into three parts, which permits the part that carries the diaphragm to be separated from the others.

The use of this objective is generally limited to the reproduction of landscapes, buildings, maps, and engravings, as fine proofs are obtained only on its being furnished with very small diaphragms, which render it very slow.

*The Periscope.*—This objective, invented by M. A. de Steinheil, is shown in Fig. 61. It is formed of

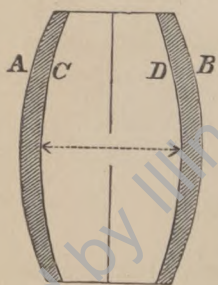


Fig. 61.

two equal meniscuses of crown-glass, having their concave surfaces towards each other. The diaphragm is placed half-way between the lenses. It possesses a chemical focus, which necessitates an adjustment after the usual focus has been obtained. With a diaphragm of an aperture of about  $\frac{f}{70}$  it covers an angle of  $100^\circ$ , and produces an image well defined over the entire field.

The following are the numerical data of this objective :—

Diameter of the lenses . . . . .		1,256
Radius of curvature of the surfaces A B .	+	1,753
" C D .	-	2,076
Distance between the two lenses . . . . .		1,256·35
Thickness of the lenses along the axis . .		125·6
Index of refraction (orange) . . . . .		1·5233
(violet) . . . . .		1·5360
Focal length of the system (visual) . . . .		10,000
" (chemical) . . . . .		9,754
Aperture of the diaphragm $\frac{f}{40}$ . . . . .		251·3

The spherical aberration of the periscope is less than that of the globe-lens, but the astigmatism is more.

*Mr. Thomas Ross's Doublet.*—The ordinary-angle doublet objective of Mr. Ross embraces an angle of about  $74^\circ$ , and the large-angle doublet about  $95^\circ$  (if the smallest aperture be used), of perfect definition. For architectural subjects, however, it is limited to an angle of  $60^\circ$ .

Fig. 62 represents a section of this objective, which consists of two achromatised meniscuses; the surface *G* being towards the object to be produced. The lenses are fixed in rings, which screw into a tube, *B E*, *B' E'*, that terminates towards the object by a larger tube, *F F'*, on which the external shutter fits. The tube containing the lenses screws on to the flange *A A'*, fixed to the camera. The diameters of the apertures of the diaphragms

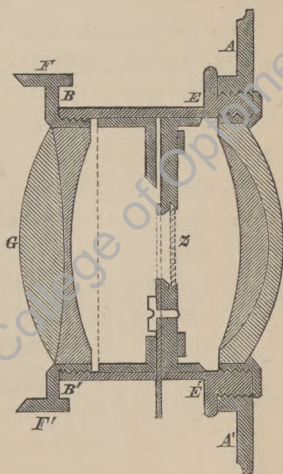


Fig. 62.

vary from  $\frac{f}{15}$  to  $\frac{f}{45}$ , and are arranged very much like the globe-lens. An internal shutter or sliding-plate, *z*, allows of the lens being opened or closed independently of the sky-shade, or external shutter. Each of the meniscuses can be used separately as a single objective.

The *Orthoscopic Lens* is formed of an achromatic meniscus, of which the convex surface is towards the object, and of a second divergent meniscus, placed at a certain distance from the former. The second meniscus consists of two simple lenses,—one, a double concave, of flint-glass, which is the nearer to the anterior lens; the other, a convergent meniscus, of crown-glass.

The orthoscopic lens, or objective, which is shown in section in Fig. 63, is the invention of M. Petzval, of

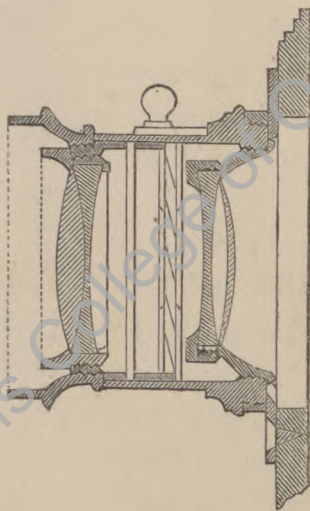


Fig. 63.

Vienna. It can be used with its entire aperture, which is about  $\frac{f}{8}$ , and then acts rapidly, but the extent of sharp image is only about half its focal length. The diaphragm is formed of imbricated plates of brass, by

which the aperture can be diminished to  $\frac{f}{30}$ , and by which the image is rendered sharp to an extent equal to the focal length of the objective. This objective produces what is called pincushion distortion, and therefore is not adapted for the reproduction of maps, buildings, engravings, &c.

*The Double Portrait Lens of Petzval.*—This objective, as constructed by Mr. Dallmeyer, of London, is shown in section of actual size in Fig. 64. It consists

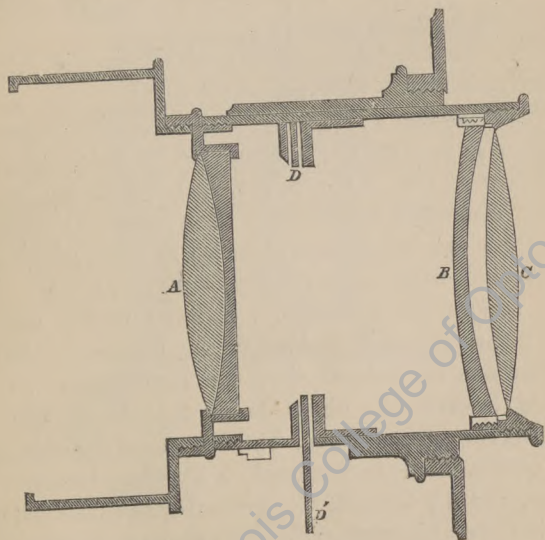


Fig. 64.

of an achromatised meniscus, nearly plano-convex, the convex face A being towards the object to be reproduced; and of a double-convex combination B C, formed of a divergent meniscus, B, of flint-glass, placed at a certain distance from the double-convex crown-glass

lens c. The diaphragm is placed at  $DD'$ , the apertures of which are so graduated that, knowing the time of exposure of one of them, that required by another is found by simple multiplication.

The field of this objective is generally much curved, if its entire aperture be used. With a large diaphragm, say  $\frac{f}{5}$  or  $\frac{f}{6}$ , it covers sharply only about  $\frac{f}{3}$  of the focal plane; but, with a smaller diaphragm of about  $\frac{f}{10}$ , the extent of sharp image is greatly enlarged, and becomes from  $\frac{f}{2}$  to  $\frac{2f}{3}$ ; with a diaphragm of  $\frac{f}{20}$ , the extent of the sharp image is equal to  $f$ .

If the diaphragm be placed as shown in Fig. 64, this objective is nearly free from distortion.

*Mr. Dallmeyer's Triplet.*—This objective, shown of actual size in Fig. 65, is composed of three achromatised meniscuses,  $AB$ ,  $CD$ ,  $EF$ , each consisting of two lenses cemented together at their common surfaces. The three meniscuses are mounted in tube, which may be covered with a pasteboard shutter at  $GH$ . The tube screws on a flange,  $IK$ , fixed to the camera. When this objective is used for landscapes, or for reproductions of natural size, the combination  $EF$  is turned towards the object to be reproduced, and  $AB$  towards the ground-glass; but when used for enlarging the combination is reversed,  $AB$  being towards the object, and  $EF$  towards the ground-glass. In order to obtain the maximum rapidity for groups and instantaneous effects, the objective should be used with the largest possible aperture; but for landscapes and reproductions, when the time of exposure is of less importance, small diaphragms may be used. The diaphragms at  $LL'$  are graduated, so as to regulate the light.

If it be desired,  $CD$  can be removed by first screwing off  $AB$ . When the combinations  $AB$  and  $EF$  are used,

the length of focus is reduced one-half, and the rapidity of actinic or photogenic action is proportionately increased; but in this case, though the system may be achromatic, the field is too much curved, and, therefore, the objective cannot be used for portraits except in special cases. When it is used for taking portraits

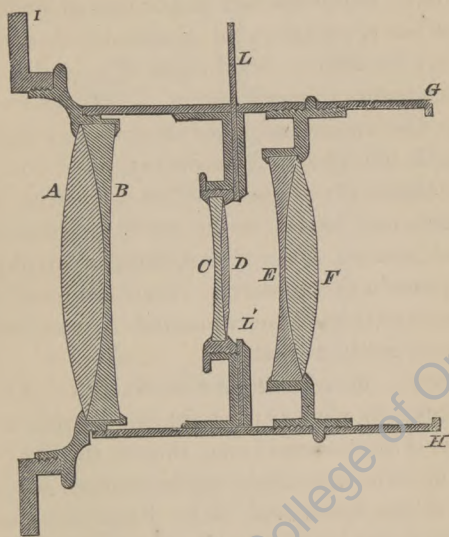


Fig. 56.

out of doors, for groups, or reproductions, the three combinations must be employed as shown in Fig. 65.

Brilliant and sharply-defined images are obtained by the use of a diaphragm the thirtieth of the focal length (seven inches), the greatest side of the image being equal to the focal length. If from any cause it be necessary to use a diaphragm of larger aperture,

the sharpness of the image does not diminish ; it is only the extent of surface sharply defined that diminishes. In practice this advantage is found so considerable, that the use of the triplet has become almost universal.

*The Flare in Photographic Lenses.*—The cause of the “flare” or “central spot” in photographic landscapes and views of buildings had puzzled photographers and opticians for a considerable length of time. By the scientific knowledge of Sir John Herschel, combined with the practical knowledge of Mr. Dallmeyer as an optician, the cause not only has been satisfactorily ascertained, but effectually removed. All double-combination objectives or lenses embracing large angles of view, and used with a small central diaphragm, had the defect, more or less, of producing a bright central spot or flare in the picture. This flare was caused by the surfaces of the back-combination lens reflecting the aperture of the diaphragm.

*Dallmeyer's Wide-angle Rectilinear Lens.*—The defect just referred to has been practically obviated by Mr. Dallmeyer's Rectilinear Lens, shown in Fig. 66. It consists of two cemented combinations, A and B, of nearly similar forms and foci. Each combination is composed of two lenses of a deep concavo-convex form of flint-glass, as  $a$  and  $a'$ , and two deep meniscuses of crown-glass, as  $b$  and  $b'$ ; the ratio of foci is such that for the qualities of glass used each combination is achromatic or actinic in itself. The diameter of the front combination A is  $\frac{1}{5}$  of the compound focus of the objective, or  $\frac{f}{5}$ , and the radius of curvature of the anterior surface  $r'$  of the flint-glass lens  $a$  is also  $\frac{f}{5}$ . The radius of curvature of the fourth or concave surface  $r^4$  of the crown lens,  $b$ , is to  $r'$  as 4 : 3. The

internal surfaces  $r^2$  of flint-glass lens  $a$ , and  $r^3$  of crown-glass lens  $b$ , are identical and cemented. The diameter of the back combination B is to that of the front combination A as 1 : 2, and the radius of curvature of the posterior convex surface  $r^8$  of flint-glass

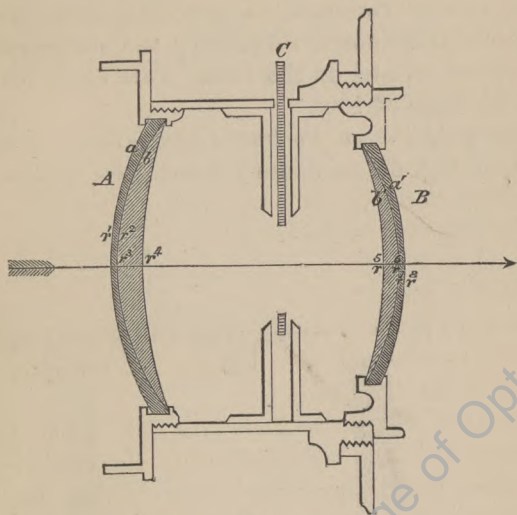


Fig. 66.

lens  $a'$  is to the radius of curvature of the anterior surface  $r'$  as 7 : 6. The radius of curvature  $r^5$  of crown-glass lens  $b'$  is to  $r^8$  as 4 : 3. The radii of curvature of the internal surfaces  $r^7$  of flint lens  $a'$ , and  $r^6$  of crown lens  $b'$ , are identical and cemented. The distance between the internal surfaces of the combinations A and B is equal to  $\frac{1}{2}$  of the compound focal length of the objective, and the diaphragm or stop, c, divides this distance in the proportion of the diameters of A and B. The largest aperture of the diaphragm for lenses

from seven-inch focal length and upwards is  $\frac{f}{1.5}$ , and the smallest  $\frac{f}{4.0}$ .

The improvements over other double-combination lenses free from distortion, and embracing large angles of view, are these,—freedom from a central spot in the resulting picture, more perfect correction both for spherical and chromatic aberrations, and greater equality of illumination throughout the entire surface of the plate covered by the lens. This objective embraces an angle of  $100^\circ$ .

*Dallmeyer's Patent Portrait Lens.*—This objective, shown in Fig. 67, combines all the good qualities of

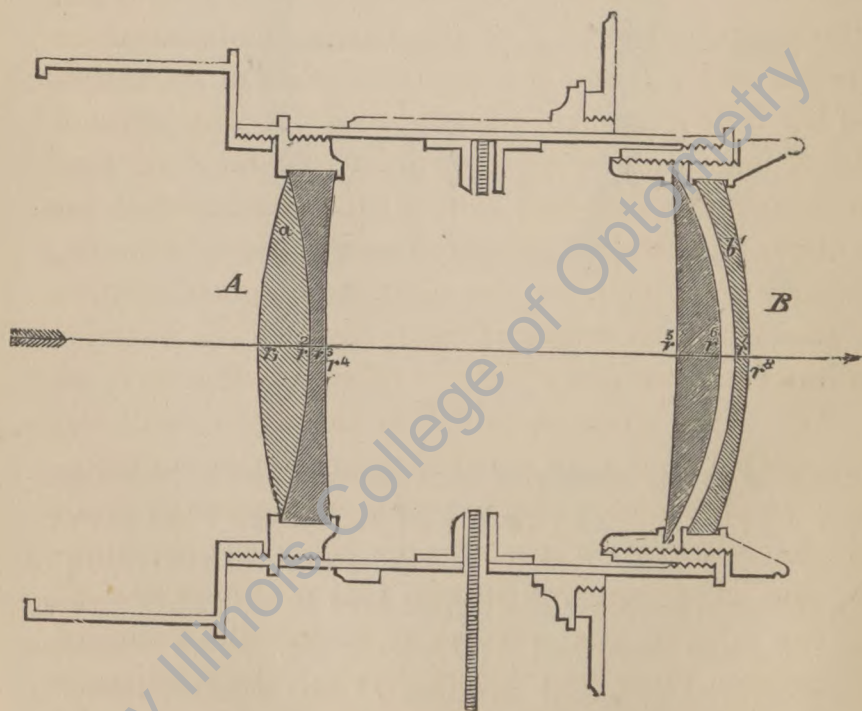


Fig. 67

the Petzval portrait-lens in its most perfect form, besides being adapted, by means of an easily-effected

mechanical adjustment, of yielding any desired amount of diffusion of focus, or distribution of definition.

It consists of two combinations, A and B, both of the same diameter. The ratios of effective aperture to focal length are  $\frac{f}{3}$ ,  $\frac{f}{4}$ , and  $\frac{f}{6}$ , according to the purpose to which it is applied.

The ratio of focal length of the anterior combination A is to the compound focus  $f$  as 9 : 6, and the focal length of the back combination B is to A as 3 : 2. The front or anterior combination A is composed of a double-convex lens of crown-glass,  $a$ , and a double-concave lens of flint-glass,  $b$ . The radius of curvature of the anterior surface  $r^1$  of the lens  $a$  is in proportion to the compound focus  $f$  of the entire combination or objective as 1 : 2, and the external radius of curvature  $r^4$  of the flint-glass lens  $b$  is to  $r^1$  as 5 : 1. The internal radii of curvature  $r^2$  of crown lens  $a$ , and  $r^3$  of flint lens  $b$ , are identical and cemented, and such that for the above focal length the combination A is achromatic, or nearly so, which, for the qualities of glass used, is the case when the ratio of radii between the anterior and internal surfaces  $r^1$  and  $r^2$  of crown lens  $a$  is as 31 : 27. At a distance equal to the diameter of the front combination A, is situated the posterior combination B, composed of a meniscus lens of crown-glass  $a^1$ , with the concave surface towards the front combination, and of a concavo-convex lens of flint-glass  $b^1$ , with the convex side outside, or facing the screen of the camera, these two lenses having their adjacent surfaces dissimilar. The radius of curvature of the adjacent or internal convex surface  $r^6$  of crown lens  $a^1$  is to that of the anterior surface  $r^1$  of crown lens  $a$  as 2 : 3; and the external radius of curvature  $r^8$  of flint

lens  $b^1$  is to  $r^1$  as 37 : 31. The radii of curvatures of the concave surface of  $r^5$  of crown lens  $a^1$ , and the concave surface  $r^7$  of flint lens  $b^1$ , are such that for the above focal length, and the lenses  $a^1$  and  $b^1$  separated from each other at the centres of their adjacent surfaces  $r^6$  and  $r^7$  by an interval equal to  $\frac{f}{60}$ , combination B is achromatic or actinic, or nearly so. For the qualities of glass employed, this is the case when the ratio of radii of crown lens  $a^1$  is  $r^6 : r^5$  as 1 : 16, and that of the flint glass lens  $b^1$ ,  $r^8 : r^7$  as 2 : 1 nearly.

This objective is free from spherical and chromatic aberration for both the axial and oblique pencils, without the use of any diaphragm, but by increasing the separation or distance between the lenses composing combination B between the limits, say of  $\frac{f}{60}$  to  $\frac{f}{20}$ , suitable means, such as a screw, being provided for the purpose, the correction for spherical aberration is thereby impaired for the moment to any required extent, and diffusion of definition obtained to suit the wishes of the operator for the time being, without, at the same time, materially deranging the other necessary corrections of the objective. This has never been accomplished heretofore. It possesses great equality of illumination throughout the entire surface covered by the lens; is entirely free from distortion without the aid of diaphragms; is well adapted for either portraits, views, or other pictures; and is economical as regards the optical means employed.

*Helsby's Heliogram.*—Mr. Helsby has recently patented an instrument by which fifty small photographs are produced at the same time on sheets gummed at the back, to be cut up and used as wafers, labels, trade-marks, &c. The lenses for this

purpose are manufactured by Mr. Thomas Ross, London.

*Dallmeyer's Rectilinear Aplanatic Lens.*—This objective, shown in Fig. 68, embraces an angle of  $70^\circ$ , and

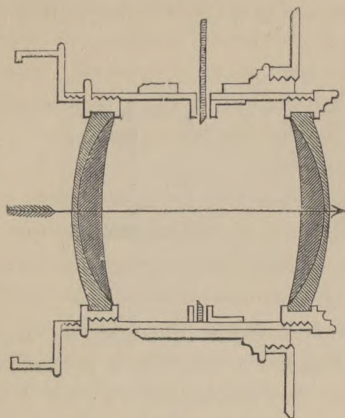


Fig. 68.

works with the full opening, *i.e.* without any stop, the aperture being  $\frac{f}{8}$ . It has therefore four times greater intensity than the wide-angle rectilinear lens of  $100^\circ$ . It is perfectly symmetrical, and is the most perfect copying lens extant; it is also well adapted for groups, dark interiors, &c., on account of its great rapidity. With the full opening it has double the intensity of the orthoscopic. Owing to its peculiarly valuable properties, it has been adopted for use by the Austrian Government. The British Government has also adopted Mr. Dallmeyer's lenses.

*Photographic Enlarging Apparatus.*—Various contrivances have been invented for enlarging carte-de-visite and other small photographic negatives to any

required size, and of a uniform sharpness over their entire surface. One of the first contrivances of this kind was—

*The American Solar Camera.*—This camera or apparatus, sometimes called Woodward's Apparatus, shown in Fig. 69, consists of a large lens *G*, called the *condenser*,

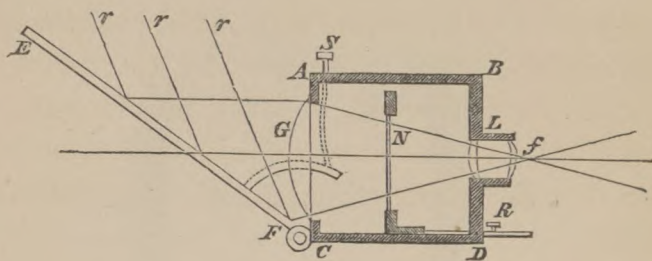


Fig. 69.

near the principal focus of which an achromatic objective, *L*, is fixed. A mirror, *E F*, reflects the sun's rays, *r, r, r*, on the condenser *G*; and the negative *N*, movable by means of a rack *R*, is placed between the two lenses at a distance which varies with that of the screen on which the image is to be formed; so that this apparatus is nearly similar to the magic lantern. The condensing lens *G* is generally 8 inches in diameter, but is sometimes made 36 inches in diameter. The larger the lens the more light it collects, and consequently the more quickly is the positive image printed.

The objective *L* should be corrected for its chemical focus, and placed a little in advance of the focus *f* of the condenser. A single or double objective serves for this purpose, but the lens of the objective, as ordinarily used facing the ground-glass, should now face the negative *N*.

The usual form of the solar camera is that of a rect-

angular box, A B C D. The mirror is attached to the box, and is adjusted by the screw s, so as always to reflect the sun's rays in the same direction, and produce an enlarged image sharply defined on a sheet of sensitive paper placed at a proper distance, and perpendicular to the optical axis of the apparatus.

*M. Wöthly's Apparatus.*—In order to prevent the vibration of the apparatus caused by the action of the screw, s, on the mirror, M. Wöthly detached the mirror from the body of the camera, and by means of cords attached to the mirror, imparted to it the motion required.

*Solar Cameras without a Reflector.*—Enlarging cameras have been invented by Mr. Stuart, in England, and by M. Liébert, in France, in which the mirror is entirely dispensed with; the sun's light being transmitted directly through the condenser. In other respects they are the same in principle as the American solar camera.

*Van Monckhoven's Dyalitic Apparatus.*—This apparatus for enlarging photographs is the same in principle as the American solar camera. The sun's rays are reflected by a mirror fixed in the shutter of the room. By means of a toothed wheel acted upon by an endless screw, the rod of which passes into the room containing the enlarging apparatus, the required position can always be given to the mirror so as to reflect the light horizontally into the condenser. The condenser is an unequal double-convex; the face turned inwards being nearly plane, and that turned outwards very convex. At a distance from the condenser equal to its diameter is a thin concavo-convex lens, the concave side of which faces the condenser, for

the purpose of correcting the spherical aberration of the condenser.

*Prevention of Fracture in the Negative.*—It frequently happened that when a condenser of large diameter was used with the American solar camera, the negative became unequally expanded, and fractured in consequence. To remedy this the negative is equally heated over its surface, and a light spring, which holds the negative in place, yields to the expansion so as to give larger space.

*The Heliostat.*—It being necessary to employ a person continually in attending to the mirror, in order to keep the solar rays always reflected in the same direction, instruments called heliostats have been invented, which cause the mirror to reflect the light in the proper direction by means of clockwork. A slight knowledge of astronomy and mechanics is requisite on the part of those who wish to use the heliostat, as the instrument requires to be set every morning, or every other morning, for the declination of the sun, &c.

*Varieties of Heliostat.*—Four or five different kinds of heliostat have been invented, viz., August's, Foucault's, Fahrenheit's, and Fahrenheit's modified by Van Monckhoven. The first is inconvenient, and can only be practically useful in the hands of an experienced astronomer. The second is complicated, and for its use requires some knowledge of astronomy. It consists of a mirror free to move in all directions about its centre; a clock regulated by escapement and pendulum; a horary, the axis of which is parallel to the axis of the earth; and a guiding-rod mounted on an arc of declination, and attached by a movable joint to a rod perpendicular to the mirror. The others are

still more complicated, and require also some knowledge of astronomy; they are, therefore, not adapted for the great majority of practical photographers.

*Enlarging Photographs by the Ordinary Camera.*—By the following methods enlargements may be produced to the extent of four or five diameters—that is, quarter-plate negatives may be enlarged to 16 inches by 12 inches, with a greater degree of delicacy, half-tone, and sharpness than by any other method in use, without the solar camera or other expensive apparatus.

The plan consists in producing by camera printing on wet collodion an enlarged transparency, which is toned to a rich black tint, and then transferred either to glazed, albumenised, or plain paper. The latter is best for large heads, and gives the effect of a very fine print on slightly albumenised paper. The following simple contrivance, shown in Fig. 70, is convenient

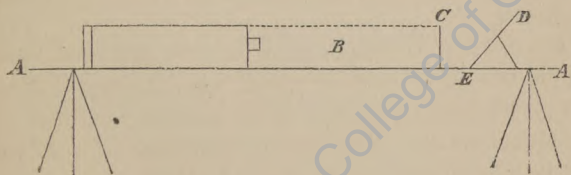


Fig. 70.

and easily arranged. A A is a board supported upon trestles; B, a copying camera; C, a frame for holding the negative, and capable of being raised or lowered, so as to bring the negative to the optical centre of the lens; D is a looking-glass, so placed as to reflect the light of the sky full upon the negative. A groove is cut through the board A A, and C and D are placed

upon a platform which moves along the board, to enable the operator to enlarge or diminish the image at pleasure; when the desired size of image is obtained, the platform is fixed by a screw, E, underneath.

The space between the negative c and the lens should, to secure the greatest brilliancy, be enclosed with a piece of black cloth, in order to prevent any light entering the lens, except that which passes through the negative; or a wooden box, painted black on the inside, may be used.

*The Magnesium Light, for producing Photographic Enlargements.*—The magnesium light has been used as a substitute for solar light in producing photographic enlargements. In all cases of using artificial light, whether the magnesium, oxycalcium, oxyhydrogen, or electric, an arrangement or apparatus analogous to that of the magic lantern is employed, the sensitive paper taking the place of the screen on which the image is projected. Development-printing is, of course, employed.

*The Convex Heliostat.*—This is a convex reflector, which has been used with very good effect upon the Ordnance Trigonometrical Survey of Great Britain and Ireland. In the great triangulation of the kingdom, the tops of mountains selected as trigonometrical stations were sometimes 100 miles apart, and upwards. These stations could not be seen, with the telescopes of large theodolites, from one another sometimes for weeks together, owing to a hazy atmosphere, &c. To remedy this the Convex Heliostat, of about 18 inches in diameter, was used in the following manner:—Let us suppose A to be a trigonometrical point on the top of a mountain, where an observer is stationed with his theodolite, and B a trigonometrical point on the top of

another mountain, the horizontal and vertical angles of which from A he is desirous of ascertaining. An assistant with a heliostat is sent to B; the assistant is supplied with data, to enable him to ascertain the direction of A from B. When the assistant arrives at B, he fixes a pole with a ring on the top, of about the same diameter as the heliostat, at a convenient distance from B, in the direction of A. He then takes the heliostat in his hand, and with it reflects the solar light through the ring on the top of the pole; this reflected light reaches the observer at A, by which means he is enabled to take his horizontal and vertical angles to B.

*The Drummond Light.*—This brilliant artificial light was first used by Lieut. Drummond, of the Royal Engineers, upon the Ordnance Trigonometrical Survey of Ireland. It was used at night, as a substitute for solar light, with the convex heliostat and others, in the manner just described.

*The Camera Obscura.*—The principle of the camera obscura has been explained in Chap. IV., Figs. 17 and 18. In the manufacture of cameras, great skill and ingenuity have been displayed during the last few years, owing mainly to the importance to which photography has attained in its application both to the fine and useful arts. Foremost among the manufacturers of camera obscuras stands Mr. P. Meagher, of 21, Southampton Row, London. At the International Exhibitions in London, Dublin, Berlin, and Paris, he has received the highest awards and medals, and the committee of the Photographic Society of Scotland in 1863, and the committee of the North London Exhibition of Arts and Manufactures in 1865, awarded him the only prize medals for very great excellence in design, material, and construction of his cameras.

*Portrait Camera.*—Fig. 71 represents a perspective view of Meagher's Improved Portrait Camera, with

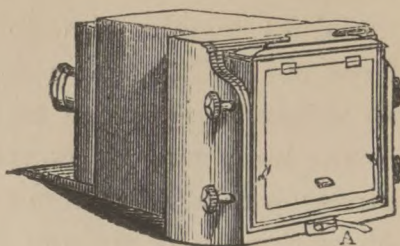


Fig. 71.

screw and rack-and-pinion action. By turning the handle A, the objective or lens is brought readily into focus.

*Meagher's Binocular Camera.*—This camera, shown extended in perspective in Fig. 72, and closed in Fig. 73, possesses a body capable of being drawn out upon what may be called the accordion, concertina, or bellows principle. It can be used for taking stereo-

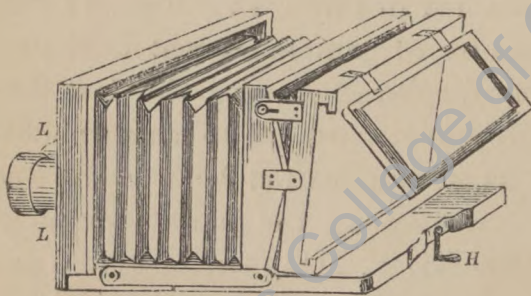


Fig. 72.

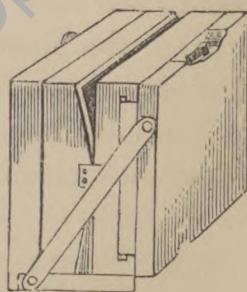


Fig. 73.

scopic views, cartes-de-visite, or single pictures on the full-size plate  $7\frac{1}{2}$  inches by 5 inches. It has a swing back: the binocular lenses L L are focussed by turning the handle H. The body of this camera is divided into two distinct chambers by a movable elastic partition.

In the construction of this camera, which is simple in form, easily put up ready for use, rigid when extended for working, and very portable, desiderata that have been long desired by photographers are most suitably adapted and elegantly combined.

In the *Kinnear Camera*, although an improvement in some respects on those previously existing, many objectionable features are retained: among these are the number of loose screws for fixing; the bottom of the camera is not attached to the body; the extension of the front in focussing renders the camera less rigid; the pyramidal form of the bellows-body renders it comparatively useless for wide-angle lenses, and for twin lenses for stereoscopic purposes.

In *Meagher's New Folding Camera* there are no loose pieces or screws connected with the camera, the focussing is effected from the back by the screw adjustment, and the bellows-body is parallel; thus rendering it available for use with the wide-angle doublet and landscape lenses, and, when fitted with a movable central partition, also available for use with stereoscopic lenses.

The folding sideboard, acting as a stay, keeps the front and back of the camera perfectly parallel and rigid when extended, as shown in Fig. 73a, and when

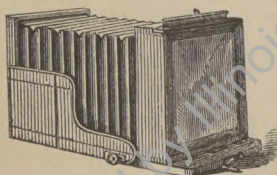


Fig. 73a.

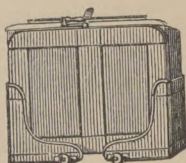


Fig. 73b.

folded keeps the bottom in position, as shown in Fig. 73b. The collodion slide and focussing screen

remain in the camera when packed for travelling as when in use; the glass of the focussing screen being effectually protected by the bottom when travelling.

Fig. 73c shows a perspective longitudinal section of the camera when extended, from which it will be seen that the sides are all parallel.

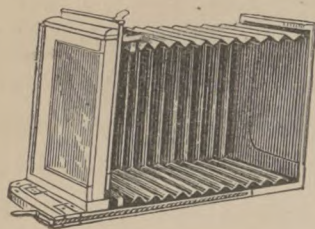


Fig. 73c.

*To erect the Camera for Use.*—Turn the sideboards (Fig. 73b) back, and the bottom drops in its position, and is then ready for use.

From the description given it might be inferred that this camera is only adapted for taking landscapes; it is, however, equally well adapted for the studio, and when made with a swing back, combines everything in the most perfect form that is required in a camera for landscape and portrait photography.

*The Camera Lucida* has come into general use for the purpose of delineating distant objects, for copying or reducing drawings, &c. The instrument in its original form, as invented by Dr. Wollaston in 1807, consists of a quadrangular glass prism, A B C D (Fig. 74), the

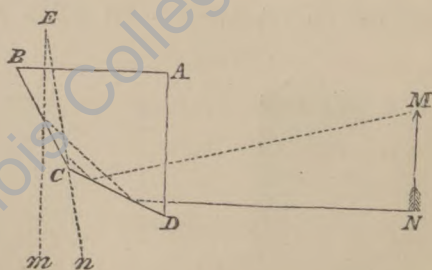


Fig. 74.

angle B A D being  $90^\circ$ , A D C  $67\frac{1}{2}^\circ$ , A B C  $67\frac{1}{2}^\circ$ , and B C D  $135^\circ$ . The rays proceeding from an object, M N, are reflected by the faces D C, C B, to the eye at E; the

observer will then see an image,  $m n$ , of the object  $M N$ , projected upon a sheet of paper at  $m n$ . If the eye be so placed that it sees into the prism with half the pupil, and past the angle  $B$  with the other half, it will obtain a distinct view of the image. The draughtsman may then trace the image upon the paper.

The size of the image projected on the paper will vary in proportion to the distance of the paper from the camera, and, therefore, the observer or draughtsman can obtain a drawing of the object on any scale he may require.

*Application to the Microscope.*—The camera lucida has been recently applied to the compound microscope, as explained in page 186, by which details and lineaments of objects so minute as to escape ordinary vision are drawn with a precision and fidelity only surpassed by the photographic process.

Various modifications and improvements have been effected in the camera lucida, particularly by Signor Amice, of Modena. In one form of the instrument the observer looks at the object through a small hole in a plane reflector, placed at an angle of  $45^\circ$  in the direction of the paper, the diameter of the hole being less than that of the pupil. In this case, while the object is seen directly through the hole, the paper and pencil are seen by reflection from the surface of the reflector surrounding the hole.

#### MICROSCOPES.

A microscope is an optical instrument for magnifying and examining minute objects. Microscopes may be divided into two classes, viz., simple and compound. The simple microscope, said to have been separately invented by Jansen and Drebell, is nothing more than a lens or

sphere of any transparent substance, in the focus of which minute objects are placed for examination. The rays of light which proceed from each point of the object are refracted by the lens into parallel rays, which, on entering the eye, placed immediately behind the lens, affords distinct vision of the object.

*The Magnifying Power of a Simple Microscope.*—The magnifying power of all such microscopes is equal to the distance at which we could examine the object most distinctly, divided by the focal length of the lens or sphere. If we say that such or such a magnifier magnifies an object three or four times, it is meant that it exhibits that object with a visual magnitude three or four times as great as that which the same object would have if viewed with the naked eye at 10 inches' distance, which is considered to be about the average distance at which most eyes would see an object distinctly. It has the further convenience of lending itself with facility to calculation, by reason of its decimal form. In continental countries—in France, for instance—25 centimètres are taken as the standard, which is very nearly equal to 10 inches, being 9.8426 inches. Sir David Brewster takes 5 inches as the distance of distinct vision with good eyes, when they examine minute objects; consequently, his magnifying powers will be only half those calculated by the ten-inch standard.

The *linear* magnifying power is the number of times an object is magnified in length, and the *superficial* magnifying power is the number of times it is magnified in surface. If the object is a small square, and we adopt 10 inches as the standard of distinct vision with the naked eye, then a lens of 1 inch focus will magnify the side of the square 10 times, and its area or surface 100 times; but if we adopt 5 inches as the

standard of distinct vision with the naked eye, then the lens will magnify the side of the square only 5 times, and its area or surface only 25 times.

It is not by the increase of superficial, but of linear dimensions, that magnifying powers are usually taken. No inconvenience can arise from this, so long as it is well understood that the linear, and not the superficial, dimension is intended. The superficial magnifying power is obtained by simply squaring that of the linear.

Microscopes may be formed in a very simple manner, by inserting drops of clear water in small apertures in a sheet of tin, or any thin solid substance. Sir David Brewster made them in this way with oils and varnishes; but the finest of all single microscopes may be executed, he states, by forming minute plano-convex lenses upon glass with different fluids. The spherical crystalline lenses of minnows and other small fish form excellent microscopes, taking care that the axis of the lens is the axis of vision, or that the observer looks through the lens in the same direction that the fish did.

*The Coddington Lens.*—A simple microscope, of very convenient form, consisting of a single lens, as shown in section in Fig. 75. This form of lens was invented by Sir David Brewster, although it has received the name of the Coddington lens, from its supposed invention by the mathematician of that name.

It is formed by cutting an angular groove round a solid globe of glass about half an inch in diameter, leaving two spherical surfaces, *A B* and *C D*, on opposite sides uncut. The angular groove, *A E C*, *B F D*, is then filled up with opaque matter, the

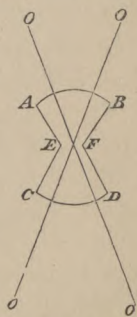


Fig. 75.

circular edge of the groove  $EF$  serving as a diaphragm between the two spherical surfaces. It is evident from the figure that the effect of the lens upon the rays  $oo$  will be the same wherever the point  $o$  may be situated; the lens, therefore, gives a large field equally well defined in all directions, and is very convenient as a hand and pocket glass. Sir David Brewster states, that when this lens is formed of garnet, and used in homogeneous light, it is the most perfect of all lenses, either for single microscopes or for the object lenses of compound ones.

#### THE COMPOUND MICROSCOPE.

In its most simple form the compound microscope is composed of a magnifying lens or combination of lenses, by which an enlarged image of a minute object is produced, and another magnifying lens, or combination of magnifying lenses, by which such image is viewed as an object would be by a simple microscope.

The former is called the *object-glass*, or *objective*, as it is always immediately directed towards the object, which is placed very near to it; and the latter the *eye-glass*, or *eye-piece*, as the eye of the observer is applied to it to magnify the image of the object. Compound microscopes are either refracting or reflecting.

*Refracting Microscope.*—A combination of lenses forming a refracting microscope is shown, without the mounting, in Fig. 76, where  $o$  is the object,  $L$  the object-glass, and  $E$  the eye-glass. The object-glass is of very short focal length, and the object  $o$  is placed in its axis a little beyond its focus. An inverted image,  $oo$ , of the object  $o$ , will be produced at a distance from the object-glass,  $L$ , much greater than the distance of

o from it; and the linear magnitude of the image will be greater than that of the object.

The observer will adjust the eye-glass E at such a distance from the image as will enable him to see it most distinctly. To estimate the entire magnifying power of such a microscope, we have only to multiply the magnifying power of the object-glass by that of

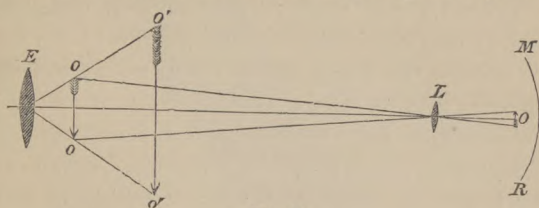


Fig. 76.

the eye-glass. If, for example, the distance of the image o o from the object-glass L be ten times as great as the distance of the object from it, the linear dimensions of the image will be ten times greater than those of the object; and if the focal length of the eye-glass be half an inch, the distance of most distinct vision being ten inches, the linear dimensions of o' o' will be twenty times those of o o, and consequently 200 times those of the object; the linear magnifying power in such a case would be 200, and the superficial magnifying power 40,000.

The distance apart at which the eye-glass and object-glass are usually mounted is about ten or twelve inches, adjustments being provided by which the distance within certain limits can be varied.

*The Reflecting Microscope.*—When the image which is the immediate subject of observation is produced by a concave mirror M R (Fig. 76) instead of the convex object-glass L, it is called a *reflecting microscope*.

The improvements which have been effected in the formation of the object-glasses of refracting microscopes have rendered these so very superior to the reflecting microscopes, that the latter have fallen into disuse.

*Conditions of Efficiency.*—These are the same as those necessary for the perfection of natural vision, viz., 1st, sufficient visual angle; 2nd, sufficient distinctness of image; and 3rd, sufficient illumination.

The greater the visual angle, the more perfect is the distinctness of the image, both as respects form and colour, provided the aberrations, spherical, chromatic, and astigmatic, are corrected by the material and form of the lenses, as explained when treating of photographic lenses, or objectives. The illumination will depend upon the intensity of the light used, and the angular aperture of the object-glass.

*Smith and Beck's Popular Microscope.*—The construction of this microscope will be readily understood by referring to Fig. 77. The body A is carried by a strong arm B, which is attached to a square bar C, that may be moved up or down by a rack-work and pinion in the lower part of the stand, when the stage D, and the mirror E, are attached.

The base F is triangular, and connected with the parts of the instrument already described by a broad stay G, which moves on centres at the top and bottom, so as to allow the end of the tube H to fit by its projecting pin into various holes along the medial line of the base. With this arrangement, if the body of the microscope be required in a more or less inclined position, as in Fig. 77, four holes are provided near the extremity of the base for the pin of the tube to fit into. A hole near the stout pin I is used when a vertical

position is wanted ; while to obtain the horizontal posi-

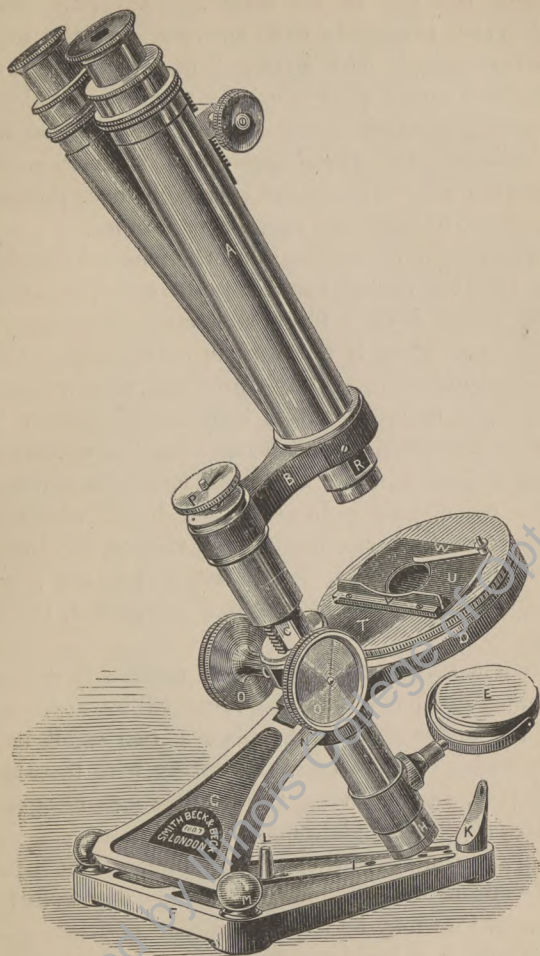


Fig. 77.

tion the pin of the tube is placed in a hole in the stud

N

κ, the inner surface of the stay G resting at the same time on the top of the stout pin L. This form of construction is entirely new, and possesses the following advantages :—It is strong, firm, and yet light; the instrument cannot alter from any particular inclination it is put into, which is not unfrequently the case when the ordinary joint works loose; and in every position the heavier part of the stand is brought over the centre of the base, to insure an equality of balance.

*Directions for Use.*—To adjust the focus of the object-glass, turn the milled heads o for a quick movement, or the milled head p for a slow one. The stage D is circular, and upon it fits a plate T; this again carries the object-holder U, which is provided with a ledge V, and a light spring W; it is held on the plate T by a spring underneath, so that it can be moved about easily by one or both hands. The small spring W is fastened to the object-holder by a milled head, which will unscrew; so that the position of the spring may be altered, to give more or less pressure upon the edge of the object, or it may be removed altogether, if necessary.

When a stage with only a flat surface is required, the object-holder U may be removed by unscrewing from the under-side of the plate T two small milled heads, which connect a circular spring with the object-holder; or, by removing the plain stage altogether, an extra simple flat plate may be substituted.

Beneath the stage there is a cylindrical fitting, for the reception of a diaphragm, or for any additional apparatus that may be required in that position.

The mirror E, besides swinging in a rotating semi-circle, will slide up or down the tube H, or it will turn on either side for oblique illumination.

The light should in general be on the left of the observer. The best is that from a white cloud on a bright day; but a satisfactory effect can be obtained from a wax or Palmer's candle, if protected by a glass, a Cambridge or moderator oil-lamp, a small paraffin or belmontine lamp, or an Argand gas-burner, provided it is not more than ten or twelve inches from the instrument.

The management of the illumination demands particular attention. That of a *transparent object* is produced by reflection from the mirror below, which should have its centre coincident with the axis of the body, and should be at such a distance that the light reflected from it may nearly converge to a focus at the object. This distance will be about two-and-a-half inches when daylight is used; but the rays from a lamp or candle, ten or twelve inches from the mirror, are so divergent, that the focus for them will be about three inches, and the mirror may have to be slid up or down accordingly.

Accurate adjustment of this focus is often required with the quarter-inch object-glass; and some details of objects, such as delicate striæ, are best seen with this glass when a strong light is thrown on them obliquely by turning the mirror on one side of the axis. With the one-inch object-glass the light is generally in excess, and has to be lessened by fitting the diaphragm under the stage. This admits only so much light as passes through one or the other of the two apertures in a small revolving disc; by which contrivance, together with sliding the diaphragm up more or less under the stage, every necessary variation can be made.

To illuminate opaque objects the light is thrown upon them from above by a small condensing lens,

mounted upon a separate stand, and capable of being turned in any direction; its focus for a lamp or candle four inches from it is about three inches; for daylight two inches. A large object can be placed upon the stage at once; but small ones are either laid on a piece of glass or held in a forceps supplied with the instrument; they fit upon the pin at the top of the small milled head, which fastens the spring on the stage; and by the ball-and-socket movement at *a*, and the sliding wire *b*, every requisite movement can be obtained. In illuminating objects from above, all light that could enter the object-glass from below should be excluded; this can be done effectually by turning over the aperture the blank space of the diaphragm.

*Wenham's Binocular Body.*—Thus far in this description the microscope has only been considered as having a single body; the addition, therefore, of the binocular body, shown in section in Fig. 78, requires a few explanations and directions for use. The purpose of the binocular microscope is to give stereoscopic vision of objects, whereby the form, distance, and position of the various parts are instantly seen; and the result is almost as striking as if the minutest object were placed in the hand as a model.

To accomplish this, the only plan hitherto known is the equal division of the rays after they have passed through the object-glass, so that the eye may be furnished with an appropriate one-sided view of the object; but the methods hitherto contrived to effect this not only materially injure the definition of the object-glasses, but also require expensive alterations in their adaptation, or, more frequently still, a separate stand; whereas the following arrangement, contrived by Mr. Wenham, is no obstacle to the use of the

monocular instrument, and the definition of the highest powers is scarcely impaired. It consists of a small prism mounted in a brass box A, which slides into an opening immediately above the object-glass, and reflects one-half of the rays, which form an image of the object, into an additional tube B, attached at an inclination to the ordinary body C. One-half of the rays take the usual course, with their performance unaltered; and the remainder, although reflected twice, show no loss of light or definition worthy of notice, if the prism be well made. As the eyes of different persons are not the same distance apart, the first and most important point to observe in using the binocular is that each eye has a full and clear view of the object; this is easily tried by closing each eye alter-

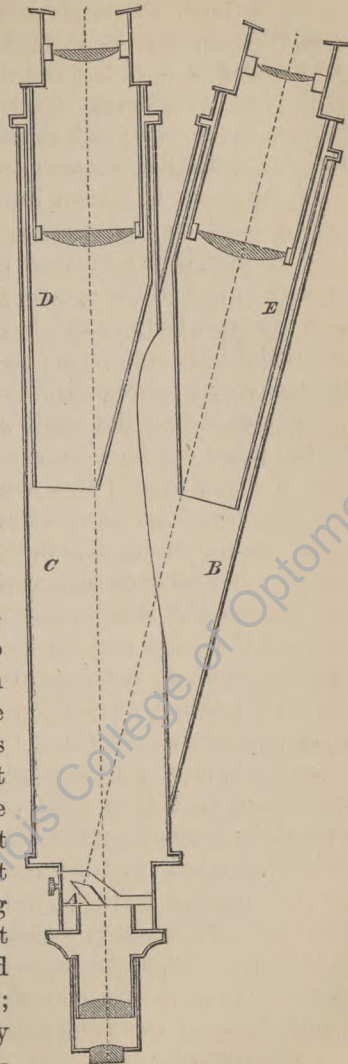


Fig. 78.

nately without moving the head. When it may be found that some adjustment is necessary, by racking out the draw-tubes *D E* of the bodies, by means of the small milled head near the eye-pieces, this will increase the distance of the centres; and, on the contrary, the tubes when racked down will suit those eyes that are nearer together.

If the prism be drawn back till stopped by a small milled head on the opposite side to *R* (Fig. 77), the field of view in the inclined body is darkened, and the rays from the whole aperture of the object-glass pass into the main body as usual, neither the prism nor the additional body interfering in any way with the use of the monocular microscope.

By unscrewing the small milled head just referred to, the prism can be withdrawn altogether for the purpose of being wiped; this should be done frequently, and very carefully, on all four surfaces, with a perfectly clean cambric or silk handkerchief, or a piece of wash-leather; but no hard substance must be used. During this process the small piece of blackened cork fitted between the prism and the thick end of the brass box may be removed; but it must be carefully replaced in the same position, as it serves an important purpose in stopping extraneous light.

As the binocular microscope gives a real and natural appearance to objects, this effect is considerably increased by employing those kinds of illumination to which the naked eye is accustomed. The most suitable are the opaque methods, where the light is thrown down upon the surface; but for those objects that are semi-transparent, as sections of bone or teeth, diatomaceæ, living aquatic animalculæ, &c., the dark-field illumination, by means of the parabolic reflector (Fig. 82), will give an equally good result.

For perfectly transparent illumination it is much better to diffuse the light by placing under the object various substances, such as tissue paper, ground-glass, very thin porcelain, or a thin film of yellow bees'-wax run between two pieces of thin glass.

*Additional Apparatus.*—When the light from the concave mirror proves insufficient for any object requiring an intense transmitted light, the achromatic condenser (Fig. 79) may be employed with advantage. This



Fig. 79.



Fig. 80.

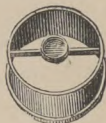


Fig. 81.

slides, by its tube, into the fitting under the stage of the instrument, in which it has to be moved up or down until the focus of its lenses falls upon the object, the light having been previously reflected in the proper direction by the flat mirror.

The illumination of opaque objects must be more or less one-sided; and in most cases it is desirable that it should be so. An illumination on any or every side, however, is obtained, provided the object is not too large, by means of the *Lieberkuhn* (Fig. 80). This is a silvered cup, which slides upon the front of the object-glass; and light thrown upwards by the mirror will be reflected by it down upon the object. It will then be found that, by slightly varying the inclination of the mirror, every necessary alteration in the direction of the illumination can be obtained. The *Lieberkuhn* here shown is intended for the one-inch object-glass. It is in most cases necessary, when using the

*Lieberkuhn*, to slide a dark well (Fig. 81) under the stage, to prevent any light entering the object-glass direct from the mirror.

*Dark-field Illumination* is, to appearance, a means of seeing a transparent object as an opaque one. The principle, however, is that all the light shall be thrown under the object, but so obliquely, that it cannot enter the object-glass unless interrupted by the object. This is best accomplished by Wenham's Parabolic Reflector (Fig. 82).



Fig. 82.

It may be easily understood by reference to Fig. 83,

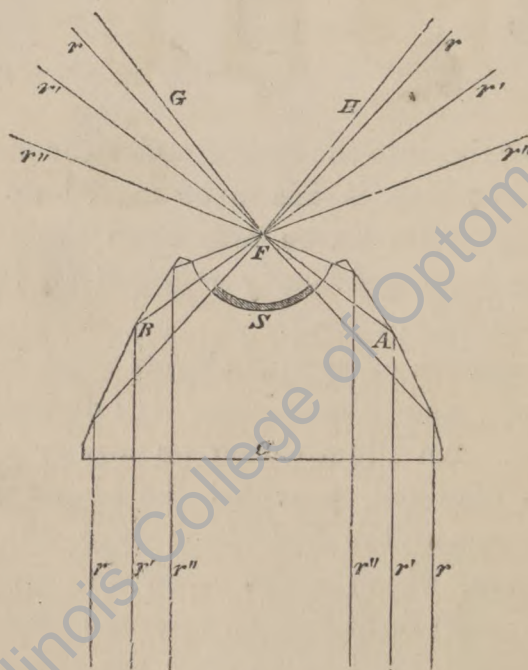


Fig. 83.

which represents it in section A B C, enlarged, and shows that the rays of light  $r$   $r'$   $r''$ , entering perpendicularly at its surface c, and then reflected by its parabolic surface A B to a focus at F, can form no part

of the largest pencil of light admitted by the object-glass and represented by  $G F H$ ; but an object placed at  $F$  will interrupt the rays and be strongly illuminated. A stop at  $s$  prevents any light from passing through direct from the mirror.

In this microscope, the parabolic reflector fits under the stage by the tube  $A$  (Fig. 84), and the adjustment

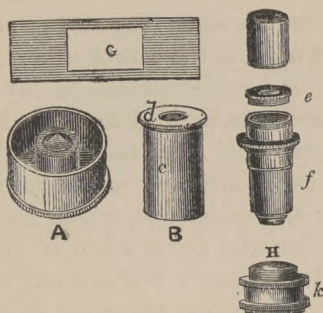


Fig. 84.

of its focus upon the object (which is when its apex almost touches it) is made by giving it a spiral motion when fitted in; that is, carefully pushing it up or down at the same time that it is turned round by the milled edge  $BB$  (Fig. 82). As the rays of light must be parallel when they enter it, a flat mirror, which in this case should be added to the instrument, is generally used; daylight will then require only direct reflection, but the rays from an artificial source will have to be made parallel by putting the condenser between the light and the mirror, about  $1\frac{3}{4}$  inch from the former, and  $4\frac{1}{2}$  inches from the latter. Nearly the whole surface of the mirror should be equally illuminated, which may be tested by temporarily placing upon it a card or piece of white paper. Parallel rays can also be obtained

from the concave mirror, if the light is put about  $2\frac{1}{2}$  inches from it.

*The Application of Polarised Light.*—Polarised light, invaluable to some microscopists, and to others a beautiful appliance by which many objects otherwise almost invisible are shown in every imaginable colour, can be applied to this microscope by the following apparatus :—A Nicol's prism as a polariser A (Fig. 84) fits, and can be turned round, under the stage ; another prism, B, slides in the place of the cap of either eye-piece, and also revolves ; or by unscrewing its outer tube *c*, and its cap *d*, it screws, as *e*, in the place of the back stop, *f*, of either object-glass, and then the object-glass, together with the prisms, is attached to the nose-piece of the microscope by the adapter H, which has a revolving fillet at *k*. When the prism B is over the No. 2 eye-piece the field of view is considerably cut off ; and although it is not so when the prism is screwed above the object-glass, yet the definition is then somewhat impaired ; its position, therefore, must be regulated by the character of the object. When only alternate black and white images are given by the prisms alone, a plate of selenite, *g*, will produce coloured ones.

*To Draw by the Camera Lucida.*—To draw an object the camera lucida is used. It slides on in the place of the cap of either eye-piece, with its flat side uppermost, as shown in Fig. 85. The body of the microscope must be in a horizontal position, and the whole instrument has to be raised until the edge of the prism is exactly 10 inches from a piece of paper placed upon the table. If the side of the case be used for this purpose, the proper distance is exceeded by three-quarters of an inch ; but the paper may easily be raised this amount by some pad. The light must be so regulated

that no more than is really necessary is upon the object, whilst a full light should be thrown upon the paper. Only one eye is to be used ; and if one-half of the pupil be directed over the edge of the camera lucida or prism the object will appear upon the paper, and can be

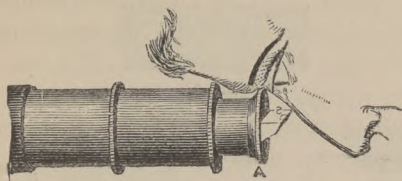


Fig. 85.

traced on it by a pencil, the point of which will also be seen. Should any blueness be visible in the field, the prism is pushed too far on, and should be drawn back until the colour disappears. Substituting in the

place of the object a piece of glass ruled into 100ths and 1,000ths of an inch, termed a micrometer (Fig. 86), its divisions can be marked on the same or another piece of paper, and by comparing them with the sketch the object can be most accurately measured. These

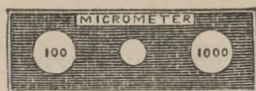


Fig. 86.

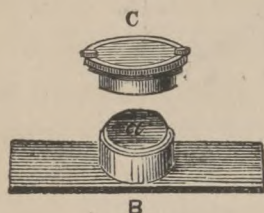


Fig. 87.

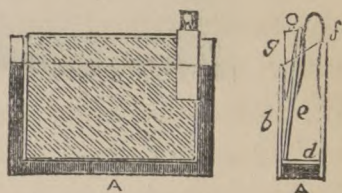


Fig. 88.

divisions, also, if compared with a rule divided into inches and tenths, will give the magnifying power; thus, supposing  $\frac{1}{100}$  of an inch when marked on the paper measured  $1\frac{1}{10}$  inch, the magnifying power would be 130.

*The Live Box* (Fig. 87) hardly needs description; the object is confined between the glass, *a*, of the lower part B, and that of the cap c; the distance between them can be varied by sliding the latter more or less on. As the thin glass is only dropped into a slight recess in the top of the cap, and is held there by the heads of the two screws, it can easily be taken out for wiping, or be replaced by another when broken.

*The Glass Trough* (Fig. 88), for larger objects in water, must be used with its thinner plate of glass *b* in front. The modes of confining such objects, and keeping them near the front surface, must vary according to the occasion. For many it is a good plan to place a piece of glass *e* diagonally in the trough, its

lower edge being kept in its place by a strip, *d*, at the bottom; then, if the object introduced is heavier than water, it will sink till stopped by the sloping plate. Sometimes a very slight spring, *f*, may be applied behind this plate to advantage, with a wedge, *g*, in front to regulate the depth.

Arrangements are made for all those parts which may require cleaning. Thus, the parabolic reflector unscrews from the tube; the Nicol's prisms will push out of their fittings; and the camera-lucida prism can be taken out by turning aside the plate that covers it.

When the movement of the object requires greater nicety than a direct action from the hand can give,

the plain stage may be taken off, and replaced by a *stage with mechanical movements* (Fig. 89). By this arrangement, the plate *a*, with a fitting sliding up or down, will receive the object, which can also be moved side-

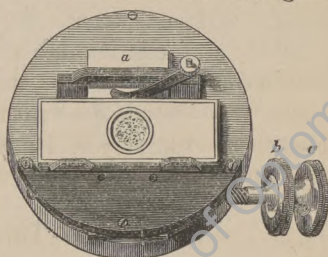


Fig. 89.

ways; these two movements forming a quick adjustment, the slower movements in rectangular directions being given by turning the milled heads *b* and *c*, which, for convenience in use, are placed on the same spindle. For rotation of the object, the whole stage may be turned upon the bottom stage-plate, which is central with the body, and consequently the part of the object that is under examination will always remain in the field of view during the rotation.

The magnifying power of this microscope varies, according to the object-glasses and eye-glasses used, from 40 times to 350 times the linear dimensions of the

object, or from 1,600 times to 122,500 times the superficial dimensions of the object.

*Various Forms of the Microscope.*—In order to adapt microscopes to the convenience and the ease of observers, various methods of mounting are adopted, depending on the purposes to which they are applied, their price, and the skill and taste of the maker. It is desirable that the stand and mounting possess simplicity of construction, portability, smoothness, and precision in the action of all the moving parts, and such a form of construction as may cause any vibration imparted to the stand to be equally distributed over every part of the mounting. These objects are completely attained in all the mountings of the best English and continental makers. The opticians in London who have become eminent as makers of microscopes are—Mr. Ross, Smith and Beck (now R. & J. Beck), Mr. Dallmeyer, Horne and Thornthwaite, and Mr. Pillischer.

#### THE TELESCOPE.

*Principle of the Instrument.*—The telescope is an optical instrument for viewing distant objects, by increasing the apparent angle under which they are seen without its assistance; and hence the effect on the mind of an increase in size or a magnified representation of the object. The word “telescope” is derived from two Greek words, which signify “at a distance,” and “I view.” The invention of the telescope is one of the most important acquisitions that the sciences ever attained, as it unfolds to our view the wonderful mechanism of the heavens, and enables us to obtain data for astronomical, nautical, and engineering purposes.

The principle is identical with that of the compound

microscope. An image of the object is produced by means of a concave reflector or a converging lens, and this image is viewed with a microscope composed of one or more converging lenses. Telescopes consist, therefore, of two classes, reflectors and refractors; in the former the image is produced by concave reflectors, and in the latter by lenses.

The simplest construction of the telescope consists of two convex lenses so combined as to increase the apparent angle under which distant objects are seen. If we take a convex lens, of say 8 inches' focus, as an object-glass, and another, of say 2 inches' focus, as an eye-glass, and place them at a distance apart equal to the sum of their foci, or 10 inches, we obtain a telescope suitable for viewing distant objects transmitting parallel rays; but when the object is comparatively near, the distance between the two lenses must be increased to adjust for distinct vision; on this account the eye-glass is mounted in a tube, sliding within another tube, in which the object-glass is fixed, and, therefore, can be drawn out for near objects.

*The Astronomical Telescope.*—The common *astronomical telescope*, shown in Fig. 90, is of the same principle of construction as that just described. It consists

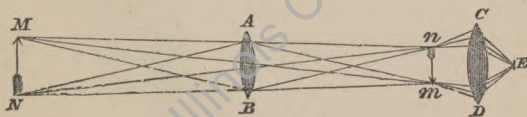


Fig. 90.

of two convex lenses A B, C D, the former of which is the object-glass, and the latter the eye-glass, from being near the eye E.  $m n$  is an image of any distant object M N. Huygens made a telescope on this principle, of

which the focus of the object-glass was 123 feet in length, and the diameter of the aperture 6 inches, the focal length of the eye-glass being  $6\frac{1}{2}$  inches. With instruments 12 and 24 feet long he discovered the ring and the fourth satellite of Saturn. In order to use object-glasses of great focal length without the incumbrance of long tubes, or incurring cost, Huygens placed the object-glass in a short tube at the top of a very long pole, so that the tube could be turned in any direction upon a ball and socket by means of a cord, and brought into the same line with another short tube containing the eye-glass which he held in his hand. The magnifying power of the astronomical telescope is found by dividing the focal length of the object-glass by that of the eye-glass.

*The Galilean Telescope.*—This telescope, which was the one used by the illustrious Galileo, from whom it derived its name, differs in nothing from the astronomical telescope excepting in a plano-concave or double-concave eye-glass  $c d$  (Fig. 91) being substituted for the convex one.

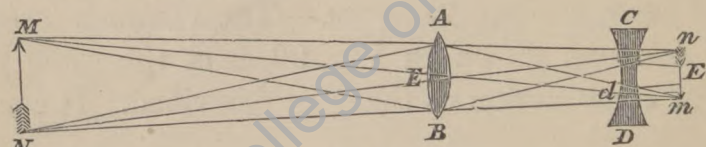


Fig. 91.

*Opera Glasses.*—From the nature of the construction of the Galilean telescope, it is susceptible of but little improvement; hence it is seldom used except for opera-glasses, in which the shortness of its construction renders it available. The distance between the two lenses is equal to the difference of their focal lengths, and the magnifying power is in the ratio of their foci, as in the astronomical telescope.

*The Newtonian Telescope.*—A longitudinal section of this instrument is shown in Fig. 92. It was invented by Sir Isaac Newton, from whom it derives its name.

A B is a concave mirror, and  $m n$  the inverted image which it would form of the object from which the rays M N proceed. But before the light reflected by the

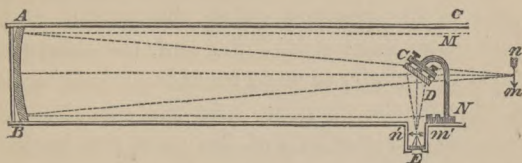


Fig. 92.

mirror A B reaches the image  $m n$ , it is received upon a plane reflector  $c d$ , placed at an angle of  $45^\circ$  with the axis of the telescope. The image  $m' n'$  is thus formed at the side, so that we can magnify this image with an eye-glass E, which causes the rays to enter the eye parallel. In this case the observer examines the object by looking in at the side of the telescope in a direction at right angles to its length.

On account of the great loss of light caused by reflection in the Newtonian telescope, Sir David Brewster has proposed an achromatic prism formed of crown and flint glass as a substitute for the mirror  $c d$ , by which the image is refracted in an oblique direction to the axis of the instrument.

The original telescope constructed by Sir Isaac Newton's own hands is preserved in the library of the Royal Society, London.

*Herschelian Telescope.*—Sir William Herschel, after having constructed several reflecting telescopes on the Newtonian principle, varying from seven to twenty feet

in length, completed in 1789 his forty-feet telescope, by which, on the very day it was completed, he discovered the sixth satellite of Saturn. The great speculum of this telescope measured 4 feet in diameter, and the area of its reflecting surface was consequently 12·566 square feet, its thickness being  $3\frac{1}{2}$  inches, and its weight 1,050 lbs. The open end of the telescope being directed to that part of the heavens under observation, and the speculum being fixed at its lower end, the observer was suspended in a chair, so as to be able to look over the lowest edge of the opening. As the speculum was a little inclined to the axis of the tube, the image was formed at about two inches from the lowest part of the edge of the opening, where it was viewed by the observer with suitable eye-pieces.

The great quantity of light obtained by this speculum or mirror enabled its celebrated constructor to use a magnifying power of 6,450 when examining the fixed stars; a power which greatly exceeded any which had been previously employed.

The telescope was mounted on a platform, which revolved in azimuth, or horizontally, on rollers. It was placed between four ladders, which served both as a framework for its support and as a means of reaching the upper end of the great tube. The ladders were united at the upper ends by being bolted to a cross-bar, to which the pulleys were attached. The telescope was raised or lowered by one system of pulleys, and the gallery in which the observer stood by another. The pulleys were worked by a windlass placed on the platform. As the frame of this instrument had decayed, it was taken down and another telescope of smaller size erected in its place by Sir J. F. W. Herschel, with which many important observations have been made.

*The Rosse Telescope.*—The largest and most powerful instrument of celestial investigation ever constructed was made by the late Lord Rosse, at Parsonstown, Ireland. The clear aperture is six feet in diameter, and consequently the area of its reflecting surface is 28·274 square feet, whilst that of Herschel's great telescope was only 12·566 square feet. The tube is 52 feet in length. This instrument is so constructed that it may be used either as a Newtonian telescope—that is, the rays proceeding along the axis of the great speculum are received at an angle of  $45^\circ$  upon a second small speculum, by which the image is thrown towards the side of the tube where it is examined by the eyepiece—or otherwise. Two specula have been provided for the telescope, one of which weighs  $3\frac{1}{2}$  and the other 4 tons, composed of copper and tin, in the proportion of 126 parts by weight of the former to  $57\frac{1}{2}$  of the latter.

When directed towards the south the tube can be lowered until it is nearly horizontal; towards the north it can only be lowered to the altitude of the pole. It is so counterpoised as to be moved with ease in the required direction.

“I have enjoyed the great privilege of seeing this noble instrument,” says Sir David Brewster, “one of the most wonderful combinations of art and science that the world has yet seen. I have in the morning walked again and again, and ever with new delight, along its mystic tube, and in the evening, with its distinguished inventor, pondered over the marvellous sights which it discloses—the satellites, and belts, and rings of Saturn; the old and the new ring, which is advancing with its crest of waters to the body of the planet; the rocks, and mountains, and valleys, and

extinct volcanoes of the moon; the crescent of Venus, with its mountainous outline; the system of double and triple stars; the nebulae and clusters of stars of every variety of shape; and those spiral nebular formations which baffle human comprehension, and constitute the greatest achievement of modern discovery."

*Nasmyth's Telescope.*—In this instrument, invented by Mr. James Nasmyth, of Manchester, the rays, after reflection from the great speculum, are received either upon a small speculum or prism placed in the axis of the tube between the focus and the great speculum. By the small speculum or prism the rays are reflected at right angles to the axis of the tube, and the image is formed in a small tube inserted in one of the trunnions upon which the instrument turns, where it may be viewed by an eye-piece as usual. This arrangement possesses the important advantage that while the great tube is moved in altitude, the small tube in the trunnion is fixed, so that the observer can survey the whole meridian or any other vertical circle without changing his place.

By means of a turntable, like those used on railways, the instrument is moved in azimuth, or horizontally. Upon the upper surface of the turntable the frame supporting the instrument and the seat of the observer are placed. Every requisite motion can be given to this telescope by the observer himself.

*Binocular Telescope.*—In Fig. 93 is shown a binocular telescope and case with straps. It may be used for marine, military, racing, or tourist purposes, and is very portable and convenient. By turning the screw between the two tubes, the two eye-glasses are brought to the proper focus at the same time.

*The Stereoscope* is an optical instrument of modern

invention for representing in apparent relief and solidity all objects, by combining into one image two plane representations of these objects, as seen by each eye

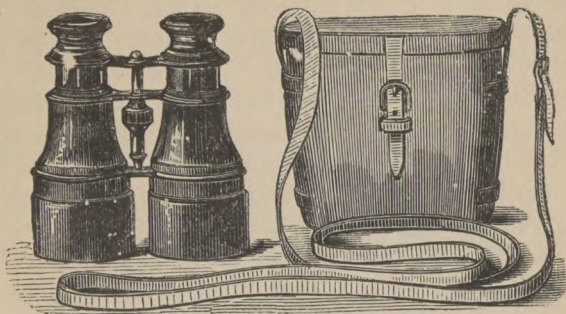


Fig. 93.

separately. The stereoscope has been made in different forms, the most general being *binocular*—that is, applied to both eyes, as shown in Fig. 94. It consists

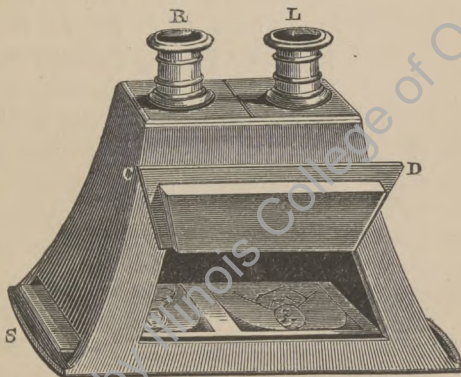


Fig. 94.

of a pyramidal box, blackened inside, and having a lid, *c d*, for the admission of light when necessary. The top of the box consists of two tubes; in one of which, *r*,

is an eye-glass to be used by the right eye, and in the other tube, *L*, is an eye-glass to be used by the left eye. The tubes containing the eye-glasses are sometimes so constructed as to suit different persons whose eyes are more or less apart, and move up and down to suit eyes of different focal lengths. A great variety of very beautiful binocular pictures have been taken photographically, suitable for the stereoscope. These pictures are called "slides." If we put one of these slides into the horizontal opening *s*, and place ourselves behind *R L*, we shall see, by looking through *R* with the right eye, and *L* with the left eye, the two pictures on the slide combined in one, and in the same relief as the object or scene they represent.

The name "stereoscope" is derived from two Greek words, one of which signifies "solid," and the other "to see."

The lenses of the stereoscope are formed by cutting a double-convex lens *A B C D* (Fig. 95) in two by a plane, *B D*, passing through the centre of the lens. Two *optically* eccentric lenses are then cut out of these, so that the diameter of each shall be equal to the radius of the original lens. A section of the original lens is shown in Fig. 96, from which it will appear that the two optically eccentric lenses *A E*, *E C* will have their thickest part at *E*, and their thinnest at *A* and *C*, while the geometrical centres are at *F* and *G*.

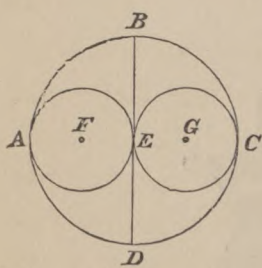


Fig. 95.

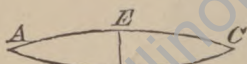


Fig. 96.

If the two lenses *A E*, *E C* be set with their edges *A* and *C* towards each other in the two eye-holes *R*, *L* (Fig. 94), whose distance apart is equal to that of the

eyes, and let a *slide* be placed before them at a distance equal to their common focal length, the two pictures on the slide will be made to coincide and unite in one by the refraction of the lenses, and the eyes will see the combined picture in stronger relief than if the original object were placed before them.

The author of this treatise has recently seen a new design of a binocular stereoscope, made at the manufactory of Mr. Meagher, 21, Southampton Row, London, which is likely to become very popular, as it can be sold at a very low price, and thus brought within reach of the great mass of the people, affording them at the same time both innocent recreation and instruction of the highest order.

*Revolving or Magazine Stereoscope.*—This is an arrangement for the exhibition of a number of slides, varying from 25 to 100, according to the price, at evening parties and social gatherings. By means of a handle, which revolves, a fresh picture is presented to the observer at every half-turn of the handle.

*The Graphoscope.*—This is an optical instrument, shown in perspective in Fig. 97, for viewing large and small photographs, stereoscopic slides, drawings, medals, engravings, and other objects of art. The most minute details are caused to appear singularly clear and vivid. It further serves as an easel, upon which any work requiring a magnifying glass may be executed.

To open it for viewing objects, raise the platform—under which is the large lens sliding on two brass rods—to the inclination desired. Turn the lens to the position in the diagram, and adjust it to a suitable height. Raise the easel perpendicular with the platform, and place the object upon it. The brass arms can extend the field of view. The required focus

is obtained by moving with the two hands the easel along the groove through the middle of the board towards the lens.

To convert it into a stereoscope, put back the lens

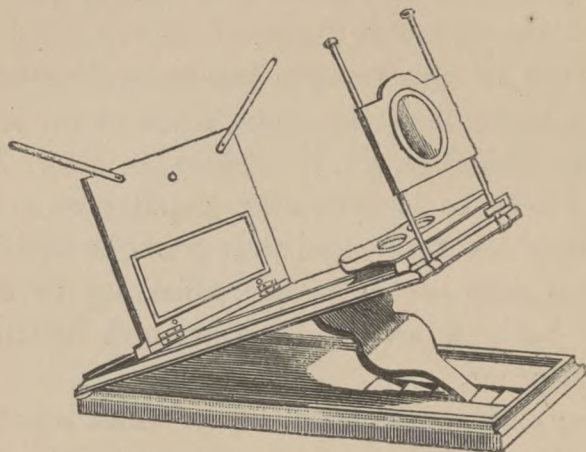


Fig. 97.

into its place under the platform, and raise up the frame with the two stereoscopic lenses. Move the easel so as to suit the vision. This is all that is required for opaque slides. For transparent slides, raise the folding camera which is under the frame. A small ring with elastic band fastens the camera to the frame, and makes it stand firm. Place the transparent object on the easel, and obtain the focus as before. Transparent objects require good light immediately behind the easel; by day the sunlight; by night a lamp.

*The Kaleidoscope.*—This optical instrument, invented by Sir David Brewster, is for the purpose of producing, in endless number and variety, beautiful forms, and exhibiting them so that they may be copied and rendered permanent in various kinds of manufacture. It consists of two oblong pieces of looking-glass placed edge to edge, and inclined to each other at an angle of

60°. Thus arranged, they are fixed in a tube of tin or brass of suitable size, an end view of which is shown in Fig. 98, where the circle  $A C B$  represents the tube, and  $A B$  and  $A C$  the ends of the pieces of glass. One end of the tube is covered with two discs of glass, between which objects are placed loosely, so that they can fall from side to side and assume an infinite variety

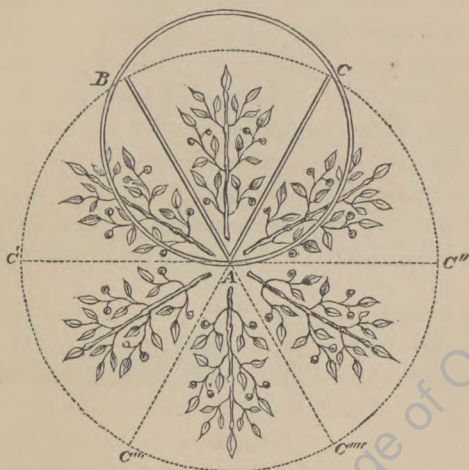


Fig. 98.

of casual positions. The outer disc is of ground-glass, to prevent the effect being marred by the view of external objects. The other end of the tube is covered by a diaphragm with a small eye-hole in its centre, through which the observer looks at the objects contained in the cell between the discs at the other end. Not only are the objects seen, but their reflection also in each of the inclined glasses; and when the angle of inclination is 60°, the object will be seen five times repeated, in positions symmetrically disposed round the

line formed by the edges at which the glasses touch each other.

The observer, looking through the eye-hole of the kaleidoscope, sees a circle whose apparent diameter  $c c'''$  is twice  $A c$ , the breadth of the looking-glass. The circle is divided into six angular spaces, two of which are the first reflections, and other two the second reflections of the inclined glasses. The other two consist of the actual space included between the glasses, and a similar space opposite to it, which receives at the same time the third reflection of both glasses, which overlies each other and appear as only one image.

For the purpose of extending the power of the kaleidoscope, and introducing into symmetrical pictures external objects, whether animate or inanimate, the inventor applied a convex lens  $L L$  (Fig. 99), by means

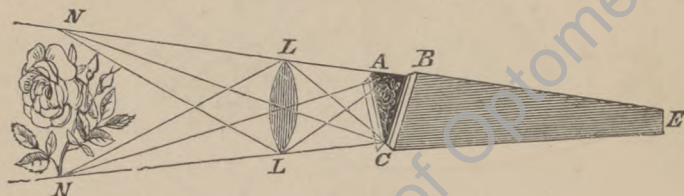


Fig. 99.

of which an inverted image of a distant object,  $N N$ , is formed quite close to  $A B C$ , the ends of the reflectors. In this construction the lens is placed in one tube and the reflectors in another; so that by pulling out or pushing in the tube next the eye  $E$ , the images of objects at any distance can be formed at the place of symmetry, that is, near the ends of the reflectors.

*Varieties of Form.*—The kaleidoscope may be constructed with the reflectors inclined at any angle which is in an aliquot part of  $360^\circ$ .

*The Quadrant* is an optical instrument, used by officers in the royal and merchant navies, for the pur-

pose of ascertaining the altitude of the sun, moon, &c., with the view of finding the latitude and longitude of a ship at sea. The quadrant is shown in Fig. 100. *AB* is the limb, divided into degrees, &c.; *c* is the vernier, attached to the bar *D*, which revolves on a pivot at the centre of the limb, and carries a microscope,

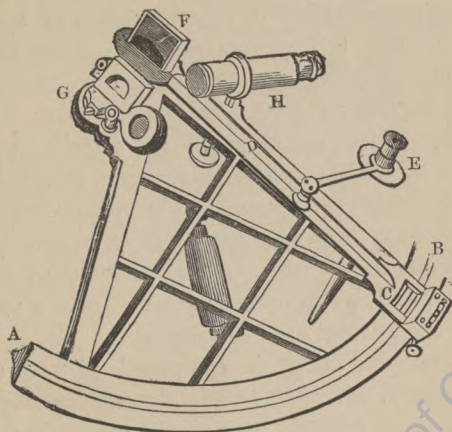


Fig. 100.

*E*, for reading the angle; *F* is a mirror, also attached to the bar *D*, which reflects the sun or moon to the horizon; *G* is another mirror, the half of which is not silvered, so that half the disc of either luminary may be seen reflected from it by the telescope *H*, and the other half of the disc seen at the same time to touch the distant horizon, where sky and water apparently meet. When the lower edge of the disc, or "lower limb," touches the horizon, the angle, as shown by the vernier, is then read off, which is the angle of altitude at the time, allowance being made for "dip" and atmospheric refraction.

*Sextants and Octants.*—These optical instruments are used for the same purpose as the quadrant, and are similarly constructed in all respects, excepting that the limb of the quadrant embraces a greater angle.

*The Theodolite* is an optical instrument, shown in Fig. 101, used by engineers and land-surveyors, for the purpose of measuring horizontal and vertical angles. It consists essentially of a circular plate or limb, supported in such a manner as to be horizontal, and divided on its outer circumference into degrees and parts of degrees; the vertical semicircular limb, for measuring vertical angles; and the parallel plates, in the lower of which is a female screw, adapted to the staff-head, which is connected by brass joints with three mahogany legs, so constructed as to shut together and form one round staff—a very convenient form for portability, and, when opened out, to make a very firm stand, be the ground ever so uneven.

The horizontal limb is composed of two circular plates, L and V, which fit accurately one upon another. The lower plate projects beyond the other, and its projecting edge is sloped off and graduated at every half-degree. The upper plate is called the vernier plate, and has portions of its edge sloped off, so as to form with the sloped edge of the lower plate continued portions of the same conical surface. These sloped portions of the upper plate are graduated to form the verniers, by which the limb is subdivided to minutes. The five-inch theodolite represented in the figure has two verniers  $180^\circ$  apart. The lower plate of the horizontal limb is attached to a conical axis passing through the upper parallel plate, and terminating in a ball fitting in a socket upon the lower parallel plate. This axis is hollowed to receive a similar conical axis, ground

accurately to fit it, so that the axes of the two cones may be exactly coincident. To the internal axis, the upper or vernier plate of the horizontal limb is attached,

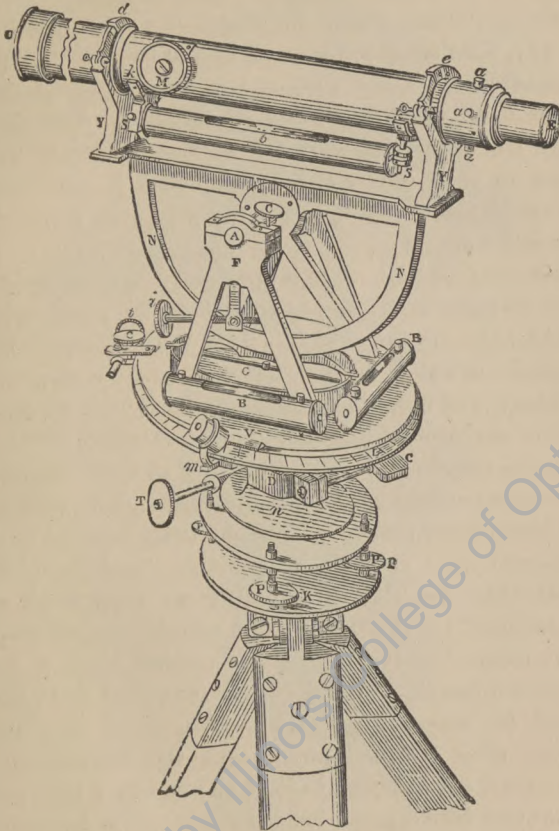


Fig. 101.

and thus, while the whole limb can be moved through any horizontal angle required, the upper plate only can also be moved through any desired angle, when the

lower plate is fixed by means of the clamping screw *c*, which tightens the collar *D*. *T* is a slow-motion screw, which moves the whole limb through a small space, to adjust it more perfectly, after tightening the collar *D* by the clamping screw *c*. There is also a clamping screw, *c*, for fixing the upper plate to the lower, and a tangent screw, *t*, for giving the upper plate a slow motion upon the lower when so clamped. Two spirit levels, *B B*, are placed upon the horizontal limb at right angles to each other, and a compass *G* is also placed upon it in the centre between the supports, *F F*, of the vertical limb.

The vertical limb *N N* is graduated on one side at every 30 minutes, each way from 0 to 90°, and subdivided by the vernier, which is fixed to the compass box, to single minutes. Upon the other side is engraved the number of links to be deducted from each chain for various angles of inclination, in order to reduce distances measured on ground rising or falling at these angles to the corresponding horizontal distances. The axis *A* of this limb must rest in a position truly parallel to the horizontal limb upon the supports *F F*, so as to be horizontal when the horizontal limb is set truly level, and the plane of the limb *N N* must now be perpendicular to its axis. On the top of the vertical limb *N N* is attached a bar that carries two *Y*s (so called from their shape), for supporting the telescope, which is secured by two clips *c d*, and underneath the telescope is a spirit level *s s*, attached to it at one end by a joint, and at the other by a capstan-headed screw. The horizontal axis *A* can be fixed by a clamping screw *c*; and the vertical limb can then be moved through a small space by the slow-motion screw *i*.

*The Transit.*—This name is applied to two differently

constructed optical instruments, one of which is used by astronomers to observe the transit of planets and stars across the meridian; the other, shown in Fig. 102,

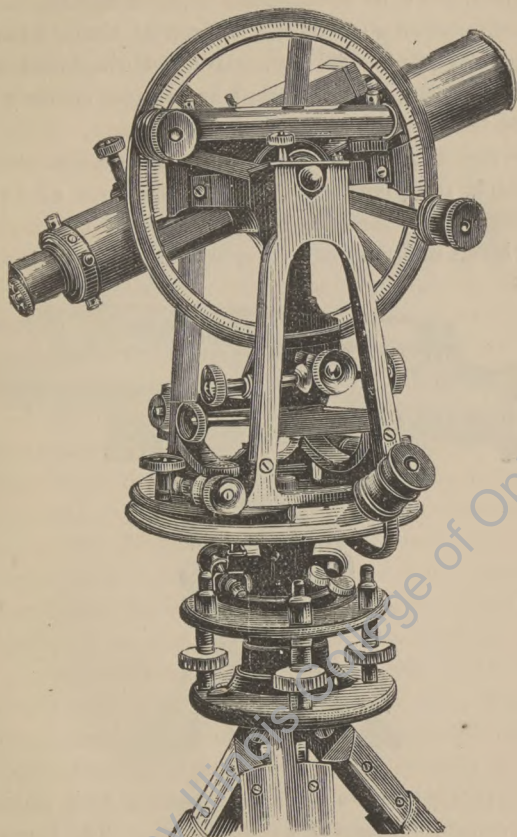


Fig. 102.

is used by civil engineers and land surveyors for measuring angles as with the theodolite. The transit used by the latter differs from the theodolite principally in this

respect—that in the transit the telescope can turn completely over, so as to look both backward and forward, while in the theodolite it cannot do so without taking it out of the Ys, or causing the whole of the instrument above the upper plate of the horizontal limb to revolve through an angle of  $180^\circ$ . In the United States and Canada the engineer's transit has almost entirely supplanted the theodolite.

*The Spirit Level* is an optical instrument used by engineers, surveyors, &c., for the purpose of finding the difference of heights between two or more places. Spirit levels differ more or less in their construction, and

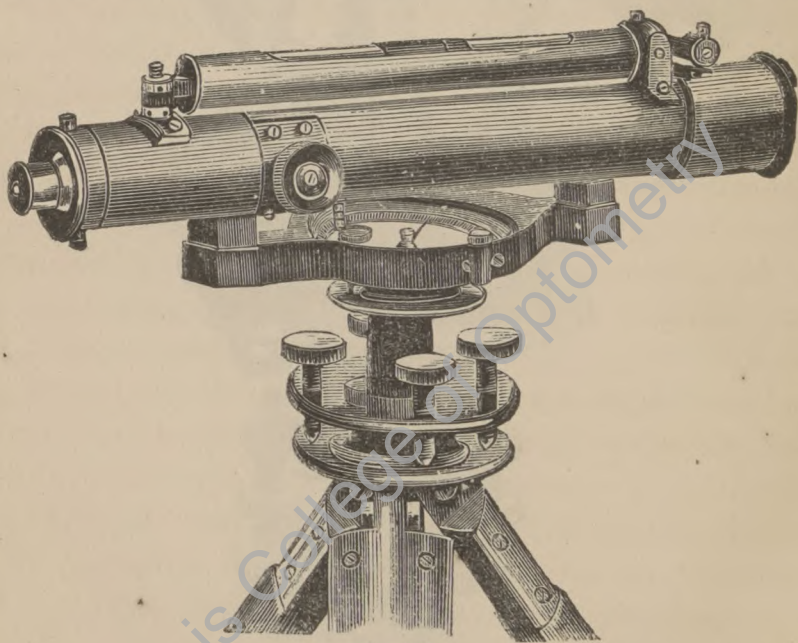


Fig. 103.

have therefore received different names, such as the Y level, Troughton's, and Gravatt's level, or the "Dumpy." The last is shown in Fig. 103. They all essentially consist of a telescope to which a spirit level is attached, resting on a horizontal bar. The parallel plates and tripod are exactly like those of the theodolite already described.

*Optical Toys.*—A great variety of optical toys owe their effects to the continuance of impressions upon the retina after the objects which produced them have altered their positions. Toys of an amusing character, called thaumatropes, phantaskopes, phenakistoscopes, &c., are constructed upon this principle. A moving object which assumes different positions in performing any action is represented in the successive divisions of the circumference of a circle in the successive positions it assumes. By causing the disc to revolve, these pictures are brought in rapid succession before an aperture through which the eye is directed, so that the pictures representing the successive attitudes are brought one after another before the eye at such intervals that the impression of one shall remain until the impression of the next is produced. In this manner the eye never ceases to see the figure, but sees it in such a succession of attitudes as it really assumes.

*The Phenakistoscope, or Magic Circle,* is a beautiful and amusing instrument on the same principle. It consists of a circular disc of cardboard, or other material, eight or ten inches in diameter, having twelve slits placed at equal distances in its margin, and in the direction of its radii. This disc can be made to turn rapidly about its axis; and if we look into a mirror through one of the slits when it is revolving, they will appear to stand still in the mirror, owing to the motions of the object and its image being equal and opposite. If a figure were placed beneath each slit, each figure seen in the mirror would be stationary. If the figures were eleven in number, instead of twelve, they would appear to move in one direction; and if they were thirteen, they would appear to move in the opposite direction. Let us now suppose twelve gates to

be drawn on a separate disc smaller than the main one, and placed upon it so as not to interfere with its slits; these gates will stand still during the revolution of the disc. If we then place thirteen horses with their riders near the gate, one horse just before he begins to leap, the second horse with its fore-legs raised from the ground, and all the other horses in the different positions of leaping, till the thirteenth horse reaches the ground, the effect will be that each horse and its rider will come up to the slit through which we look faster than the gate; and as each gate arrives, the horse will have advanced  $\frac{1}{13}$  of  $\frac{1}{12}$  of the circumference of the disc; that is, in one complete revolution it will have moved forward through  $\frac{1}{13}$  of the circle. Had there been eleven slits it would have moved backwards. Now during this motion the horse has taken thirteen different positions in succession, and therefore leaps the gate.

In like manner, there are twelve hedgerows, with several hounds, each of which is represented in thirteen different positions, so that they appear in the act of crossing the hedges, and we have exhibited before us a portion of a fox-hunting scene which produces a very agreeable excitement.

*The Anorthoscope* is an optical instrument, by means of which two discs, revolving with different velocities, rectify, or make regular, and multiply an extremely shapeless and irregular figure. This instrument, and also the phenakistoscope, were invented by M. Plateau, who might easily have invented simpler names for them.

## CHAPTER XVII.

THE PRINCIPLES OF OPTICS APPLIED TO VARIOUS  
USEFUL PURPOSES.

*Photo-zincography.*—One of the most useful applications of the laws of optics is that of producing a photographic facsimile of any subject, such as a manuscript, a map, or a line engraving, and transferring the photograph to zinc, thereby obtaining the power of multiplying copies in the same manner as is done from a drawing on a lithographic stone, or on a zinc plate. This process is called photo-zincography.

The first part of the process concerns the production of a negative photograph on glass of the object of exactly the same size as the original. This is obtained by the ordinary wet collodion process. When the lens and camera are in adjustment, the plate is covered with the sensitive coating, exposed, developed, and fixed in the ordinary way, and then immersed in a saturated solution of chloride of mercury (corrosive sublimate). When well whitened by the action of the salt, it is removed, washed with water, and then with a solution of hydrosulphate of ammonia, consisting of ten parts of water to one of hydrosulphate of ammonia of commerce.

In this manner the ground of the negative is rendered extremely dense, without affecting the clearness of the detail. When dried and varnished it is ready for use.

The quality of the paper used is a point of much importance. That which has been found best suited for the purpose is a semi-transparent kind, with a

smooth surface, known by the name of engravers' tracing-paper.

Solutions of gum arabic and bichromate of potassa are prepared by dissolving one part by weight of gum arabic in two parts distilled water, which may be called solution A ; and 1 oz. of bichromate of potassa in 10 oz. distilled water, which may be called solution B. When required for use, one part by measure of solution A is mixed with two parts of solution B, and the paper is coated over evenly with the mixture by a flat camel-hair brush, and dried. It is then exposed under the negative in the usual way. The time required for printing varies from ten minutes in diffused light to two minutes in sunlight. When all the details appear distinct it should be removed.

The next step is the coating of the whole surface of the print with an even layer of a greasy ink, which is of two kinds; the nature of the object photographed determining what kind is to be used. If it is, for instance, a line engraving of a close nature, a *thin ink* is applied in the smallest possible quantity to prevent clogging; if, on the other hand, the object is of an open nature, as in manuscript printing, a *thick ink* with more tenacity is employed. The thin ink is composed of 5 oz. of middle linseed-oil varnish, and 1 oz. of lamp-black. The thick ink of 2 oz. of middle linseed-oil varnish, 4 oz. of wax,  $\frac{1}{2}$  oz. of tallow,  $\frac{1}{2}$  oz. Venice turpentine,  $\frac{1}{4}$  oz. of gum mastic, and  $1\frac{1}{2}$  oz. of lampblack. In order that the ink may form an even coating on the paper, a zinc plate is charged with it by means of a roller, taking care to cover the plate as thinly but as evenly as possible. The paper is laid face downwards on the plate, passed through a lithographic press two or three times, and then removed from the

plate. It is next placed with the inked surface upwards in a flat porcelain dish—about an inch deep, half full of warm water, to which has been added about a teaspoonful of thick gum water—and passed down to the bottom, where it is retained by holding down a corner with a glass rod. The surface is gently brushed, while underneath the water, with a flat camel-hair brush, and the ink will quickly be removed where it overlies the soluble gum, while it will be retained on the parts which constitute the image, and where the action of the light penetrating the transparent portions of the negative has rendered it insoluble. As soon as the whole of the ink has been removed from the ground of the print, the water is poured off and cold water is poured in, and made to flow backwards and forwards over it to remove the gum. After two or three washings in this manner it is hung up to dry, and when dry it is ready for transferring to zinc or stone.

The process of transfer is of two kinds, varying with the nature of the ink which has been used. If the thin ink has been applied, the print is transferred by the “anastatic” process. For this purpose the surface of the zinc plate is polished with emery powder, and made as smooth as possible. The print is placed, for about ten minutes, between sheets of paper which have been dampened as uniformly as possible with a mixture of nitric acid and water, in the proportion of five parts of water to one of concentrated acid. A sheet of paper dampened with the acid is laid on the zinc plate, and both are passed between the cylinders of a copper-plate printing press, and the acid being forced on to the zinc, slightly etches the surface. The paper is then taken off, and the film of nitrate of zinc formed on the plate

is carefully cleared off with a handful of blotting-paper. The print is next laid on its face downwards, and both are passed once through the press. The paper is then pulled off, and the transfer is gummed and brought up by going lightly over the surface with a sponge dipped in printing ink softened with olive oil. As soon as all the detail appears strong, it is etched with a very weak solution of phosphoric acid in gum water, the strength of the acid solution being so regulated that a drop placed on a smooth zinc plate for three minutes slightly tints or dulls the polish. The transfer is then ready for printing in the usual way.

If thick ink has been used in the preparation of the print, the mode of transferring is somewhat different. The plate is prepared by rubbing the surface with fine sand and water and a zinc muller between sheets of paper damped as uniformly as possible with water; it is then laid face downwards on the plate, covered with two or three sheets of paper, and passed two or three times through an ordinary lithographic press. The sheets of paper being removed, it is damped at the back with gum water till its adhesion to the plate is so lessened that it can be easily pulled off. After the transfer has been gummed, brought up, and etched as in the anastatic process, the ink is cleared off with turpentine, and the design is rolled up with printing ink. Impressions can then be taken from it.

Having described the two methods of transfer, it is necessary to treat further of the considerations which determine the nature of the ink used, and consequently the mode of transfer.

The action of the warm water, in which the print is immersed, on the insoluble gum, is to cause it to swell, and the ink which overlies the lines formed of insoluble

gum expands likewise. It is evident, therefore, that if the object photographed is of a close nature, as a fine engraving, the expansion of the ink-lines may be sufficient to bring them into contact while the print is in the water; and, when once they have coalesced, they will not again separate when the gum resumes its natural size on the drying of the print, and there will be a continuous shade of ink instead of lines. In such a case the quantity of ink applied should be as small as possible, and, to enable a light but even coating to be laid on, it must also be thin; and, as a consequence of the small quantity of ink used, the transfer must be effected on a smooth plate by the anastatic process, because, to make a successful transfer to a grained plate, a larger quantity of ink is necessary.

On the other hand, as impressions from a grained plate are, as a rule, better than those from a smooth plate, and as a larger number can moreover be struck off if the object photographed is so open that there does not appear to be any likelihood of the lines coalescing in the water, it is better to use the thick ink in the preparation of the print, as the use of that ink is a *sine quâ non* for the employment of the latter mode of transfer.

*National Manuscripts, how Photographed.*—By the process just described, fac-similes and translations of the most interesting documents preserved in the Record Office, London, have been made by the Ordnance Survey Department, Southampton. These documents illustrate the changes in the English language, and in caligraphy, from the time of William the Conqueror to Queen Anne.

*Scotch National Manuscripts.*—The most interesting documents preserved in the Register Office, Edinburgh,

and in private libraries in Scotland, are being also copied by the Ordnance Survey Department in the same manner.

*Photo-lithography.*—This process, analogous in principle to lithography, gives very good half-tone, with an appearance of very delicate granulation. Instead of a stone or plate with a grained surface, the organic body employed is left on the plate, and by its absorption of moisture in the degree in which it is left soluble, enacts the part of a lithographic stone. The process is as follows:—A mixture of isinglass, gelatine, and gum, evenly spread upon a well-polished metallic surface, and previously treated with an acid chromate, has been found to give most satisfactory results, as a greasy ink adheres well to the gelatinous surface, and is taken up in proportionate quantities, according to the intensity of the gradations of light and shade.

To render the organic film sensitive it is treated with an acid chromate. The ordinary chromate and bichromate salts are not suited to the purpose, as they do not impart sufficient sensitiveness; the alkaline trichromates when used alone are likewise incapable of producing perfect impressions, and it is only by adding a certain proportion of acid, or some body possessing a strong affinity for oxygen, as formic, gallic, pyrogallie acids, &c., or some soluble salt produced by the last-named acids, or even certain reducing salts, as hyposulphates, sulphates, bisulphates, hypophosphites, phosphites, &c., to the trichromate, that a suitable compound is obtained.

After printing the plates are well washed and dried, and are then ready for the application of the ink by means of a pad or roller, the surface of the film presenting the appearance of a graduated mould, or an

aqua-tint plate without grain. When the ink is applied the hollow portions of the plate become receptacles for the same, while the higher surfaces remain uncovered; the water contained in the pores of those parts of the gelatine which have undergone no change by the action of the light repels the ink, forming minute granules, while the insoluble portions of gelatine (the concave parts which have been acted upon by the light) take up a thin or thick deposit of ink, in proportion as those parts have been rendered more or less impenetrable to water. This, the printing process, is a combination of engraving and lithography. Plates produced in this manner are capable of furnishing about seventy good impressions; after that number has been struck off the prints commence to lose vigour, and become somewhat imperfect; but fresh plates are easily prepared.

*Photographic Decorations of Porcelain, Glass, &c.*—A very important economic application of photography to the decoration of porcelain, glass, &c., with gold, silver, and other metals, consists in producing an ordinary silver image on a collodion film, and then, by toning processes, converting this image into any other metal which may be necessary. For a gold design the image is toned with chloride of gold; for a design the colour of steel the image is toned with chloride of platinum; for a black metallic design the image is toned with chloride of iridium; for a brown design the image is toned with the chloride of palladium. A design in a metal of one colour can be obtained by first toning the image by the proper metallic salt, and then saturating the film with a solution of some other salt. The collodion film, treated in the manner indicated, is then transferred to the porcelain, and the salt reduced to the metallic state by heat.

*Influence of the Solar Rays on the Growth of Plants.*—

It has been already stated that the solar beam consists of three different principles, viz., light, heat, and actinism. Seeds will not germinate under the influence of light deprived of that principle upon which chemical change depends. Mr. Robert Hunt made some experiments with common cress and turnip seed placed upon moist earth, and slightly covered with sand. One-half of the seed-bed was screened from the rays by a blackened board, and the other freely exposed. Under the shaded half the germination was between two and three days in advance of the exposed portion. This experiment was repeated, using a glass trough, containing a weak solution of bichromate of potash half an inch in thickness, over the illuminated portion. This solution admitted the permeation of 87 parts of the luminous, or *light* rays, 92 of the calorific, or *heat* rays, and 27 of the chemical, or actinic rays; the object being to ascertain if any greater retardation was produced by the luminous rays, from which the chemical principle was to a considerable extent removed, than by the pure solar beam, which he regarded as a compound of 100 parts of each—light, heat, and actinism. The result was that the seed under the bichromate of potash solution, or yellow medium, did not germinate until five days after the seeds in the dark part of the bed.

*Germination of Seeds entirely prevented.*—Upon substituting a solution of sulphate of chromium and potash, which admitted the permeation of 85 parts of light, 92 parts of heat, and only 7 of actinism, the germination was entirely prevented in four experiments; and in the fifth, ten days after the seeds in the dark had germinated, half-a-dozen seeds of cress showed symptoms of germination. These experiments

were many times repeated, and always with similar results. We have thus satisfactory evidence that the solar beam, deprived of the principle or power of chemical action, arrests the development of the plant by preventing the vitality of the germ from manifesting itself.

*The Origin of Vitality in Seeds.*—In another series of experiments on common cress, mignonette, ten-week stocks, and minor convolvulus, when from 93 to 95 parts of actinism, 48 parts of heat, and only 25 parts of light passed through, it was found in every instance that the seeds influenced by the chemical or actinic rays germinated in one-half the time which the seeds placed in the dark required. It is evident, therefore, that the spring of vitality in seeds is due to some power or principle of solar origin, distinct from the light-and-heat principle.

*How the Vital Power is exerted.*—The manner in which this power is exerted in seed beneath the surface of the soil is not clear at present; we know not if it is a mere disturbance of something already diffused through matter, or an emanation from the sun; all we are enabled to declare is, that the germination of seeds is more rapid under the influence of the actinic rays, separated from the luminous ones, than it is under the influence of the combined solar radiations, or in the dark.

*The Development of Roots from Plant Cuttings.*—In the practice of planting cuttings, the use of blue glass screens is highly advantageous, as the light and heat rays are partly absorbed, whilst the actinic rays pass through and accelerate the development of roots.

*Light Rays essential to the Formation of Woody Fibre.*  
—Dr. Daubeney in England, and Dr. Gardner in

America, made numerous experiments, which show that the decomposition of carbonic acid increases with the increase of light rays, that it is more rapid under the influence of the yellow ray than any other, and that the largest quantity of woody matter is found in those plants which have had the largest amount of light. The author of this treatise, who travelled extensively over the United States and Canada, where the settlers, in clearing the primeval forests for cultivation, generally cut or hew the trees at about three feet above the surface of the ground, found, in thousands of the stumps he examined, that the radius of the stump from the core southward was invariably longer than the radius from the core northward, and, further, that the thickness of each ring of the stump was greater towards the south than towards the north. This clearly proves that the direct influence of the solar beam, or the directly combined influence of light, heat, and actinism, produces more woody fibre than is produced by diffused light.

*The Value of Seeds speedily determined by Blue Glass.*  
—The commercial value of seeds depends upon the extent that the vital principle is active in them. For instance, if one hundred seeds of any sort be sown, and the whole germinate, the seed will be of the highest current value; but if ninety only germinate, its value is about ten per cent. less; if eighty, then its value falls about twenty per cent. Messrs. Lawson, of Edinburgh, extensive seed merchants, found that seeds planted in a case, the sides and cover of which were formed of blue glass, germinated in from two to five days, whereas the same kind of seeds sown in a hotbed usually took from eight to fourteen days to germinate.

*Scorching prevented at the Royal Gardens at Kew.*—

The late Sir Wm. Hooker found that the solar beams after their passage through white glass at the conservatory at Kew scorched the foliage of the plants. This scorching was prevented by the substitution of a pea-green glass stained with oxide of copper for the white glass. The pea-green glass admits the passage of sufficient rays to promote healthy vegetation, but obstructs the passage of the rays which produce the scorching.

*The Knowledge of Optics useful to the Engineer, Architect, &c.*—By the laws of optics combined with a knowledge of practical geometry, the engineer and architect are enabled to draw a representation of a building, or any other object, in perspective, or as it would appear to the eye in any given position. The projection of shades and shadows on geometrical elevations and sections of buildings, or other objects, is also dependent on the same principles.

*The Laws of Light applied to the laying of Submarine Telegraphic Cables.*—When the Atlantic cable was first laid, the currents of electricity became so feeble as to render the motion of the electric needle imperceptible to the eye, the operators not knowing whether any current was really passing along the cable or not. To test this a very small lamp of the lightest possible material was constructed with a narrow slit in it to permit the light to pass through. This lamp was placed on the electric needle with the slit facing a screen placed several feet from it. The light from the lamp passing through the slit was projected upon the screen as a bright oblong figure; the smallest motion of the needle being imparted to the lamp, caused the oblong bright spot on the screen to move over a large space, which readily indicated whether feeble

currents were passing along the cable, or had entirely ceased.

*The Illumination of Lighthouses.*—Of the many useful applications of the laws of light there are few that surpass in importance their application to the illumination of lighthouses for the guidance and protection of mariners.

Up to the year 1780 the means of illuminating lighthouses throughout the world generally consisted of wood or coal fires or tallow candles. At the period mentioned, Argand lamps and paraboloidal reflectors were first used in the lighthouse at Corduan, under the directions of the distinguished French philosopher, Borda. This method was found to have been a decided improvement upon the fires and tallow candles. The Trinity House of London sent a deputation to France to inquire into the system carried out under Borda, who reported favourably of it. In 1787 the old castle at Kinnaird-head, Scotland, was lighted by means of paraboloidal reflectors of silvered copper and Argand lamps; and in 1807, the tallow candles used at that time in the Eddystone Lighthouse, one of the most dangerous points on the coast of Britain, were obliged to hide their diminished heads by the far more brilliant and effective light of the Argand burners and paraboloidal reflectors. Soon afterwards the system became general throughout the United Kingdom.

*The Fresnelian System of illuminating Lighthouses.*—Many unsuccessful attempts had been made between the middle of the eighteenth century and the early part of the nineteenth to illuminate lighthouses by means of lenses. It is to the genius of M. Augustin Fresnel the world is indebted for the excellent system which he invented in 1819, and successfully carried out in practice three or four years afterwards.

Fresnel's system consists of plano-convex lenses arranged round a lamp placed in their common focus, and in the level of their focal plane, and form, by their union, a right octagonal hollow prism. Each lens subtends a central horizontal pyramid of light of about  $46^\circ$  of inclination, beyond which limits the lenticular action could not be advantageously pushed, owing to the extreme obliquity of the incidence of light; but Fresnel at once conceived the idea of pressing into the service of the mariner, by means of two simple expedients, the light which would otherwise have uselessly escaped above and below the lenses.

For intercepting the upper portion of the light, he employed eight smaller lenses of 500 mm. focal distance (19.68 inches), inclined inwards towards the lamp, which is also their common focus, and thus forming by their union a frustrum of a hollow octagonal pyramid of  $50^\circ$  of inclination. The light falling on those lenses is formed into eight beams rising upwards at an angle of  $50^\circ$  of inclination. Above them are arranged eight plane mirrors, so inclined as to project the beams transmitted by the small lenses into the horizontal direction, and thus finally to increase the effect of the light. Other modifications of the system were invented by Fresnel, and adapted to the peculiar circumstances in which the light was to be used.

A very important modification of Fresnel's apparatus was invented by Mr. Alan Stevenson, engineer to the Board of Northern Lighthouses, Scotland. Having been directed to convert the fixed catoptric or reflecting light of the Isle of May into a dioptric or refracting light of the first order, Mr. Stevenson proposed that an attempt should be made to construct the belt for the refracting part of the apparatus of a form truly cylin-

dric instead of octagonal; and this task was successfully completed by Messrs. Cookson, of Newcastle, in 1836. The cylindric form is the only one that can possibly produce an equal diffusion of the incident light over every part of the horizon.

Mr. Stevenson first imagined that the whole hoop of refractors might be built between two metallic rings, connecting them to each other by cement; but this would make it necessary to build the zone at the lighthouse itself, and would thus greatly increase the risk of fracture. He was therefore reluctantly induced to divide the whole cylinder into ten arcs, each of which being set in a metallic frame, might be capable of being moved separately. The chance, also, of any error in the figure of the instrument has thus a probability of being confined within narrower limits, whilst the rectification of any defective part became at the same time more easy. He also improved the arrangement of the apparatus, by giving to the metallic frames which contain the prisms a rhomboidal instead of a rectangular form, by which the amount of intercepted light becomes equal in every azimuth.

Another important improvement in Fresnel's apparatus was made by Mr. Stevenson, by substituting totally reflecting prisms for the mirrors, even in lights of the first order or largest dimensions. By this arrangement it appeared on trial of the apparatus at the Royal Observatory at Paris, that the illuminating effect of the reflecting prisms was to that of the seven upper tiers of mirrors of the first order as 140 to 87. Nothing can be more beautiful than an entire apparatus for a fixed light of the first order. It consists of a central belt of refractors, forming a hollow cylinder 6 feet in diameter, and 30 inches high; below it

are six triangularly prismatic rings of glass, ranged in a cylindrical form, and above a crown of thirteen triangularly prismatic rings of glass, forming by their union a hollow cage, composed of polished glass, 10 feet high and 6 feet in diameter.

The illuminating effect of this arrangement of lenses, as measured at moderate distances, has generally been taken at 4,500 Argand flames, the value of the great flame in the focus being about 16, thus increasing the illuminating power nearly 300-fold.\*

The dioptric or refracting system of lights used in France is divided into six orders, in relation to their power and range; but in regard to their characteristic appearances this division does not apply, as in each of the orders lights of identically the same character may be found, differing only in the distance at which they can be seen, and in the expense of their maintenance. The six orders may be briefly described as follows:—

1st. Lights of the first order, having an interior radius or focal distance of 36·22 inches (92 cm.), and lighted by a lamp of four concentric wicks, consuming 570 gallons of colza oil per annum.

2nd. Lights of the second order, having an interior radius of 27·55 inches (70 cm.), lighted by a lamp of three concentric wicks, consuming 384 gallons of oil per annum.

3rd. Lights of the third order, lighted by a lamp of two concentric wicks, consuming 183 gallons of oil per annum, and having a focal distance of 19·68 inches (50 cm.).

4th. Lights of the fourth order, or harbour-lights, having an internal radius of 9·84 inches (25 cm.), and

\* For further information on this subject, see Stevenson's "Rudimentary Treatise on Lighthouses." Weale Series. No. 47.

a lamp of two concentric wicks, consuming about 130 gallons of oil per annum.

5th. Lights of the fifth order, having a focal distance of 7.28 inches (18.5 cm.); and

6th. Lights of the sixth order, having an internal radius of 5.9 inches (15 cm.), and lighted by a lamp of one wick, or Argand burner, consuming 48 gallons of oil per annum.

These orders are not intended as distinctions, but are characteristic of the power and range of lights, which render them suitable for different localities on the coast, according to the distance at which they can be seen. This division, therefore, is analogous to that which separates the lights of the United Kingdom into sea-lights, secondary-lights, and harbour-lights, terms which are used to designate the power and position, and not the appearance, of the lights to which they are applied.

Each of the orders is susceptible of certain combinations, which produce various appearances and distinctions, such as—fixed; fixed, varied by flashes; revolving, with flashes once a minute; and revolving, with flashes every half-minute, &c.

It has been found that, in fixed lights, the French improved refracting apparatus produces, as the average effect of the combustion of the same quantity of oil, over the whole horizon, upwards of four times the amount of light that is obtained by the catoptric system of paraboloidal reflectors.

*The Ventilation of Lighthouses.*—The ventilation of the lanterns forms a most important element in the preservation of a good and efficient light. An ill-ventilated lantern has its sides continually covered with the water of condensation which is produced by the

contact of the ascending current of heated air ; and the glass thus obscured obstructs the passage of the rays and diminishes the power of the light.

*Professor Faraday's System of Ventilation.*—An important improvement in the ventilation of lighthouses was introduced by Professor Faraday into several of the lighthouses belonging to the Trinity House, and has since been adopted in all the dioptric lights belonging to the Commissioners of Northern Lighthouses. The following is a description of Professor Faraday's apparatus:—The ventilating pipe or chimney is a copper tube 4 inches in diameter, not, however, in one length ; but divided into three or four pieces ; the lower part of each of these pieces for about one and a half inch is opened out into a conical form, about five and a half inches in diameter at the lowest part. When the chimney is put together, the upper end of the bottom piece is inserted about half an inch into the cone of the next piece above, and fixed there by three ties or pins, so that the two pieces are firmly held together ; but there is still plenty of air-way or entrance into the chimney between them. The same arrangement holds good with each succeeding piece. When the ventilating chimney is fixed in its place, it is adjusted so that the lamp-chimney enters about half an inch into the lower cone, and the top of the ventilating chimney enters into the cowl or head of the lantern.

With this arrangement it is found that the action of the ventilating flue is to carry up every portion of the products of combustion into the cowl ; none passes by the cone apertures out of the flue into the air of the lantern, but a portion of the air passes from the lantern by these apertures into the flue, and so the lantern itself is in some degree ventilated.

The important use of these cone apertures is, that when a sudden gust or eddy of wind strikes into the cowl of the lantern, it should not have any effect in disturbing or altering the flame. It is found that the wind may blow suddenly in at the cowl, and the effect never reaches the lamp. The upper, or the second, or the third, or even the fourth portion of the ventilating flue might be entirely closed, yet without altering the flame. The cone junctions in no way interfere with the tube in carrying up all the products of combustion ; but if any downward current occurs, they dispose of the whole of it into the room without ever affecting the lamp. The ventilating flue is in fact a tube which, as regards the lamp, can carry everything *up*, but conveys nothing *down*.

*The Advantage Commerce has derived from Fresnel's System.*—Of the many distinguished men of exalted genius who have extended the boundaries of human knowledge by their inventions, there are but few who have conferred greater benefit on commerce and maritime intercourse than Fresnel, who deserves to be ranked among those benefactors of the species who have consecrated their genius to the common good of mankind ; and as long as commercial intercourse subsists between nations the solid advantages which his labours have produced will be felt and appreciated.

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
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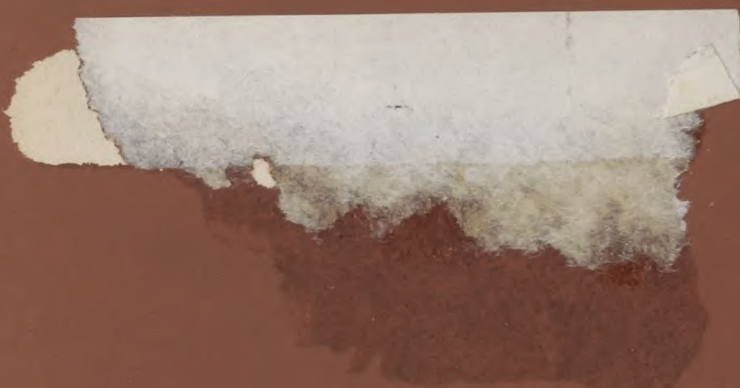


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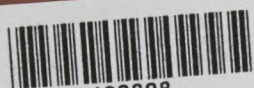
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